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Field Manual of Plant Ecology

by

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FIRST EDITION
SECOND IMPRESSION

NEW YORK TORONTO LONDON
McGRAW-HILL BOOK COMPANY, INC.
1949

FIELD MANUAL OF PLANT ECOLOGY

PRINTED IN THE UNITED STATES OF AMERICA

PREFACE

Having taught plant ecology at the University of Michigan Biological Station during the past thirty-two summers, the author has acceded to repeated requests for a manual based on this course.

The course was initiated and developed in line with Agassiz's famous maxim: "Study nature, not books," in addition to which special effort was made to use as little and as simple apparatus as possible. The aim was to work with plants at all times. Both high-school and college students can use the manual with suitable modification in any part of the country.

At the present time (1949) several excellent books are available for reference and study. While the author still maintains that fundamentally the best results are obtained when the novice explores the subject for himself with a minimum of direction and instrumentation, he is not blind to the broadening of horizon obtained from consulting certain well-chosen books dealing with ecology. To name but a few, one may call attention to the following, of which the first two are excellent textbooks for vegetational ecology, and the third is most useful for the study of individual plants.

1. Weaver, John E., and F. E. Clements, "Plant Ecology," 2d ed., McGraw-Hill Book Company, Inc., New York. 1938.

2. Braun-Blanquet, J., "Plant Sociology," translated and revised by G. D. Fuller and H. S. Conard, McGraw-Hill Book Company, Inc., New York. 1932.

3. Cowles, H. C., "Ecology," revised and enlarged by G. D. Fuller, American Book Company, New York. 1931.

4. Welch, Paul S., "Limnology" (zoological), McGraw-Hill Book Company, Inc., New York. 1935.

5. Shelford, V. E., "Laboratory and Field Ecology" (zoological), The Williams & Wilkins Company, Baltimore. 1929.

6. Clements, F. E., and V. E. Shelford, "Bioecology," John Wiley & Sons, Inc., New York. 1939.

7. SHELFORD, V. E., compiler and general editor, "Naturalist's Guide to the Americas," The Williams & Wilkins Company, Baltimore. 1926.

8. TANSLEY, A. G., and T. F. CHIPP, editors, "Aims and Methods in the Study of Vegetation," British Empire Vegetation Committee. 1926.

9. KLAGES, KARL H. W., "Ecological Crop Geography," The Macmillan Company, New York. 1942.

10. DAUBENMIRE, R. F., "Plants and Environment," John Wiley & Sons, New York. 1947.

11. OOSTING, HENRY J., "The Study of Plant Communities," W. H. Freeman and Company, San Francisco. 1948.

In the bibliographies in these books the student will find many references to additional literature.

In using this or any other manual the teacher must study over the habitats at his disposal and select certain ones for classwork together with the methods best fitted for that particular area. He should then "cruise" over the area to become absolutely familiar with the plants and endeavor to be ready to cope with any situation that may arise. Sometimes specific directions for an area will need to be made in addition to the general directions in this manual. Later in the course, areas new to the teacher as well as to the students may be studied.

In setting up the field course in plant ecology in a new area, effort should first be directed toward obtaining as detailed maps as possible. If such are not available, the teacher should make some preliminary maps himself to use until better ones can be obtained. At least one class exercise may be expected to result in a detailed map of a small part of the region. If the teacher is familiar with the ground control, aerial photographs are a great help in locating streams, lakes, roads, and trails but have to be carefully checked in determining vegetation.

With or without maps, the teacher must explore the area to discover and evaluate likely places for classwork. He should make necessary transportation arrangements, determine what and how much general and special equipment will be needed, and make direction sheets. The latter should call attention to location and special features; include questions to direct attention and

study; contain lists of species, references, and special pointers regarding write-up; and state the time at which the report is to be handed in.

In an area of many possibilities a portion of the work may take account of particular needs of certain students.

In the field, the teacher will introduce the area by pointing out its salient features, giving as much of the history as is known or pertinent; select or assign the work of the students, individually or in groups; be as available as possible to all for answering questions, checking directions, etc., and to lead a get-together in the area as soon as the field work is finished for more questioning and to summarize the data.

The student, on the other hand, should learn the time, the place, and the equipment necessary for the trip; go over the advance assignment, if there is one; get the direction sheet or the assignment for his group; complete the work in the field, recording the data in the form most suitable for incorporation in the data assemblage, make such drawings, sketches, or collections as are necessary; obtain any special directions for writing up the exercise; and hand in the report within the set time limit.

In different parts of the country, the number and variations in types of vegetation will make it necessary to select exercises that are suitable to that region. Thus all ecology courses should not be expected to be alike in the material used, although the approach and methods of studying may be quite similar.

The greater the diversity present in a region, the easier it is to utilize successional relationships as the underlying framework upon which to base the course. In most areas in nature there will be two feralarch (or wild, *i.e.*, natural) series—the one starting on bare ground as rock, known as the xerarch series, or sere, and the other initiated in the water of streams, lakes, or ponds, known as the hydrarch sere. Typical areas of associations from the early or pioneer stages, mid-stages, and final or semifinal (climax or subclimax) stages should be selected for study, individually or in groups. One should be sure to include as many of the following types of habitat as feasible:

Forests of different types on different soils, upland and lowland, rain forest, winter rain or dry forest.

Grasslands, as prairies, plains, marshes.
Deserts.
Hydric or aquatic, as lakes, ponds, streams.
Special habitats, as sand dunes, bluffs, strands, riverbanks, bogs, swamps, marshes, saltmarshes, rock, revegetation after fire or abandonment.

Under conditions of human disturbance the hemerarch series is present. The development of orchards; of lawns, pastures, meadows; of roadsides, rock-gardens, fencerows, vacant lots; or the conditions of any of the crops of an area may be studied.

Any study of factors, either with regard to individual plants or to any of the groupings in vegetation, will require the use of instruments. Specific directions for certain exercises in certain areas will be made to utilize the various available instruments one or more times in appropriate situations; hand levels in dune profiles, soil auger in soil work, tape and benchmarks in dune movement, steel tape and special compasses in surveying, tree calipers in forest studies, peat borers in peat study, while meter-sticks, pH set, and cameras may be used quite generally.

A second year in the same area will make possible necessary adjustments and improvements and will also serve as a check on past work. A series of years in the same region will permit the building up of a historical account of the vegetation and serve as a check on any predictions that may have been made.

It is at once obvious that it will not be possible to do all of the exercises in this manual in one season or one summer. It is, however, essential that the work include thorough grounding in the quadrat method in some of its forms. Tree counting, transects, charting, an exercise in mapping, familiarity with the main factors of the environment, characterization of the dominant species of the associations, and successions between the associations are fundamental and should certainly be included. At least three formal reports should be written.

At the University of Michigan Biological Station, where 16 full days are available each summer, the following program has been carried out: work in the aspen association, employing diferent quadrat and tree-counting methods, soil characterization, recovery from previous fires, community coefficients and species

analysis, on 4 days; in bogs another 4 days, studying the associations and their successional relationships in changing the bog from open water to land, work with peat; in sand dunes for 2 days, including a study of the development of dunes, the root and shoot systems of their characteristic species and a profile of the surface of the ground; aquatics for 1.5 days, during which the different groupings with the characteristics of their typical species and successional relationships are studied in lakes, streams, and beachpools; the maple-beech forest for 2 days, including a study of the dominant and characteristic ground plants, soil, and reproduction; surveying and map making 1 day; the jackpine association on 1 day, including the growth of the dominant species, the characteristic ground flora, and the successional relationships; and 0.5 day devoted to examinations. Two longer and two shorter written papers are required during the summer.

The author is indebted to Nellie B. Jacobs for many hours of stenographic work in connection with the production of this manual and to his wife, Margaret T. Gates, for her inspiration and assistance in the preparation of the manuscript.

FRANK C. GATES

MANHATTAN, KAN.
March, 1949

CONTENTS

INTRODUCTION

Purpose

The purpose of this manual is to give directions for the undertaking of beginning ecological work with the use of a minimum of apparatus, particularly elaborate apparatus. The desirability of ecological study to aid in the development of independent thinking, together with the encouragement of cooperative endeavor, is recognized. Valuable training is given an inquiring mind both in stating and in attempting to solve ecological problems. Although the basic exercises are simple and serve to introduce the subject, they can be extended to more detailed work, even to problems for actual research.

Certain experiments utilize instruments. The simpler instruments here emphasized may later be replaced by more complicated ones or by recording instruments as occasion arises. Plant ecology basically is a study of plants in relation to their environment. However, in evaluating the environment one must either use words of quite general and often indefinite meaning or take advantage of instrumental measurements. It is true enough that directions for the use of instruments are relatively easy to give. Their employment may, however, take up too much of the time that can be allowed for work in the field. I believe the balance between the plant and the instrumental sides of an ecological study should favor the plant side, wherever possible.

The experimental side of ecological work usually requires considerable time. Beginning classes therefore can seldom perform more than the simplest experiments. It may be possible for the instructor to set up the experiment and carry it along while the students make observations or read instruments at intervals during its progress. However, many students feel that they are playing an important part when they collect data for an experiment which requires a number of years to complete.

For ecological field work a knowledge of plants in every stage of their development is of prime importance. Such complete knowledge even in a given region is seldom secured. Consequently, certain field exercises need to be preceded by the naming of at least the more important species as they are pointed out, or this can be done in the classroom with herbarium specimens or pictures. The students should be provided with plant lists upon which they may make annotations as the important plants are pointed out to them. Unknown plants may be so designated until identification is possible. If the names of the plants are not known, collections should be made and numbered. Those numbers should be used when referring to the plants until their scientific names have been ascertained. Some collecting equipment, if only an old magazine or scrapbook in which to dry specimens, is important. It is always well to preserve specimens, especially of important or critical species, to permit subsequent checking of identification.

Detailed directions for the collecting of plants to make a permanent herbarium are to be found in several recent books, of which the following are among the best to consult:

Hitchcock, A. S., "Methods of Descriptive Systematic Botany," Chap. 8, John Wiley & Sons, Inc., New York. 1925.

Pool, R. J., "Flowers and Flowering Plants," 2d ed., Chap. 27, McGraw-Hill Book Company, Inc., New York. 1941.

Swingle, D. B., "A Textbook of Systematic Botany," 3d ed., Chap. 3, McGraw-Hill Book Company, Inc., New York. 1946.

A simple serviceable press may be made by nailing and clinching together three pieces of lath, each 18 inches long, and seven pieces, each 12 inches long, as a lattice for each side. Heavy cords, each with a bowline loop in one end, tightened around the press about one-fourth of the way from each end furnish the pressure to flatten the plants in drying. The plants, bent as necessary, are placed in folded sheets of newspaper. These in turn are placed between driers (strong blotting paper) in the press. Driers are taken out of the press, dried and replaced during the process of drying. Sheets of corrugated boxboard may be interspersed in the press to facilitate drying.

In getting acquainted with the plants of a region, the various botanical manuals should be employed. If one is not acquainted with the proper manuals, a publication by S. F. Blake[1] is an up-to-date listing of those used in various areas of the United States, including each of the individual states. An acquaintance with plants at their various stages can be obtained only by individual experience. Collections and their determination are a great aid in this respect. The more plants one knows, the easier it is to learn additional plants. Knowledge gained in one region is more of an aid in another region than one realizes.

Use of the Exercises

Nearly all the exercises given in this manual have at one time or another been put into active use by the author at the University of Michigan Biological Station at Douglas Lake, Cheboygan County, Michigan, and there have demonstrated their worth. Minor modifications may sometimes be necessary to fit the exercise into different regions. Getting acquainted with the vegetation of an area, the way it is built up, and the way it is related to the environment are the major objectives of field ecologists. Certain exercises, such as the quadrat method (or sample-plot method), are of such fundamental importance that it is possible to do a whole summer's work using no other method, especially in areas where there are several plant associations or types or communities of vegetation. If there are not many types of vegetation but several areas of the same type, a summer's work can be used in bringing out the closeness of agreement between the different areas.

The outcome of such study is an appreciation of what vegetation is and what factors enter into its development and spread. The ability to reconstruct the history and to predict, often in great detail, what will happen to vegetation of a given area in the course of time, may also be developed.

[1] Blake, S. F., and Alice C. Atwood, "Geographical guide to floras of the world, Part I," *U.S. Dept. Agr. Misc. Publ.* 401. 1942. For the separate states of United States only, a briefer but later annotated list is the following: Blake, S. F., "State floras of the United States," *Chron. Bot.*, **7**: 258–261. December, 1942.

Equipment

In this manual special effort is given to the setting up of exercises that utilize a minimum of special equipment. Frequently material may be present that can be set up on the spot. At such time as finer, more elaborate equipment is available, better results can be expected. There is a tendency to overemphasize the fineness of expression as against the variability of the original data, as for instance, when one records 3.333 as a measurement resulting from an *estimate* that a certain thing is 3 and about one-third units in length. The significance of figures would allow for no more than 3.3. Both instructor and student should appreciate the difference between measurement and estimation and realize that in this type of work excess of data tends to average out inconsistencies which may creep into not-too-perfect original measurements.

Student personal equipment includes a field notebook. Perhaps the simplest is the aluminum cover which may be opened to permit the insertion of ordinary notebooks of various sizes. A cover about 4.5 by 7.5 inches (13.5 by 19 centimeters) in size is in general the handiest. The fillers may be regular notebooks bound at the top or loose leaves. Paper that will not go to pieces and will not stick together upon getting wet is most desirable for field work. Pencils depend upon the preference of the individual. The 1H or 2H pencils, which mark well without smudging and do not run when wet, are the best. It is wise to have the pencil tied to the notebook and the notebook provided with a cord to hang from the student's neck.

Thin-lead, waterproof colored pencils are sometimes valuable but are not usually recommended for use in the field.

A ruler may be etched on the cover or one may cement a narrow strip of cross-ruled paper to the inside of the cover. A rubber band around one cover under which to insert the sheets which have been written upon is likewise handy.

A knapsack to carry the various items of equipment is desirable, particularly on daylong trips. A good type is a shell bag such as is used by hunters. A trowel for digging and a hunting knife are often indispensable. For quadrat work, metersticks

of some form are essential. A pair hinged to open at a 90-degree angle are often advantageous. A hand lens is also useful.

Compasses

In the field a magnetic compass is almost a necessity. Keeping directions well when one is simply coursing through an area is comparatively easy, but when one is continually stopping, turning around, and taking notes, especially in woods, it is usually impossible to maintain direction without reference to a magnetic compass. In use, hold the compass well away from any metal that would affect the needle.

Note: A watch which is running within 15 minutes of correct standard time, not daylight-saving time, may be used in sunshine as a compass with reasonable accuracy by holding the watch immediately in front of you with the hour hand pointing toward the sun. Halfway between that and 12 on the watch is due south in the Northern Hemisphere. At night knowledge of some of the stars may be advantageous; certainly any ecological worker in the Northern Hemisphere should be acquainted with the location of the polestar at the end of the Little Dipper. The two outer stars in the bowl of the Big Dipper point toward the North Pole. This is usually the easiest method of locating the polestar. It may be well to mention that the angle of declination of the polestar with the horizon is the latitude of the place of observation. The magnetic deviation of the compass in a given region may be obtained from navigation charts or other maps.

Forms

Forms for the recording of data are very useful. However, avoid sacrificing individual development of students by having too many forms prepared in advance to fill out. Setting up suitable forms is part of the student's work. It can readily be channeled to a suitable type and the form mimeographed and made available at the proper time.

Cross-ruled Paper

For the ordinary notebook, a few pages of cross-ruled paper are often distinctly advantageous in sketch mapping or drawing

parts of plants to scale. Remember that water will wash out the blue lines of blue-lined cross-ruled paper.

Maps

Maps are an important part of a student's equipment. If base maps of the local area are not available, the class can make such maps as a part of their course (see Exercise 26).

Miscellaneous Suggestions for Comfort in the Field

Clothing. While the subject of clothing is largely a personal matter, in some types of ecological work it is important that the clothing be of material which will withstand field conditions and suitable for the climate. Clothing as well as shoes should be of the sort that will dry out quickly after a soaking.

Sunburn. A coat of tan, acquired early, preferably before summer, will aid greatly in preventing undue sunburns. A day's work on sand dunes or in and out of water too often results in severe cases of sunburn. Dark glasses aid in protecting the eyes. Under severe conditions the use of creams on the face and especially the lips, as a protection, may be desirable.

Poison Ivy. If poisonous species of Rhus [*R. vernix*, poison sumac, and *R. radicans* (*R. toxicodendron*), poison ivy or "poison oak," as it may be called] are present it may be desirable to have a cake of strong laundry soap to wash with after contact with the poisonous Rhus. For long trips, calamine lotion to sooth and potassium permanganate crystals to make about a 10 per cent solution to oxidize the resin or a 5 to 10 per cent aqueous ferric chloride solution to counteract the resin may be included.

Small Items. Various small items of equipment suggest themselves, such as pocketknives, extra handkerchiefs, and extra pencils. The leader might well have a small sewing kit, with extra safety pins and a Red Cross first-aid kit. Salt tablets to counterbalance the loss of salt through the skin in hot weather should be added to the medicine kit.

Insect Repellents. Field trips in parts of the country are made most unpleasant by pests, of which mosquitoes, chiggers, black flies, deer flies, nosee-ums, and stable flies are perhaps the most common. There are several repellents on the market, but those

that are best and may be used in the smallest quantity contain pyrethrum extract. Citronella or pennyroyal in olive oil is commonly used but is not so effective as oils containing pyrethrum. A preparation sold under the trade name d-Ter is a moderately effective insect repellent. Insect Repellent 612 was successfully used in the tropics during the past war. Tars also are good repellents but have the disadvantage of staining garments. Sprays from flit guns may be useful in camp. Most sprays are a form of mineral oil, or some light oil. If the spray oil is fortified with pyrethrum extract or some other good repellent, it is most effective. The Pyrethrum-aerosol Bomb, recently developed, is more effective than sprays and considerably more convenient to carry and use. Wearing extra clothing may sometimes be necessary to repel pests. Mosquito nets and heavy gloves are essential in some areas at certain times of the year. If mosquitoes are not too abundant I have found that if one remains quiet in the place where he wishes to take notes and kills the mosquitoes that come to him within the first 3 or 4 minutes, usually he can then be free to take notes for about 5 or 10 minutes. Any movement which disturbs the vegetation, however, brings more mosquitoes.

Bee Stings. If the stingers of bees are pulled out the reverse of the way they went in, the discomfort will generally be but temporary. If a little soda is available it will neutralize the formic acid. Wet clay mud is also effective.

Poisonous Snakes. In areas in which poisonous snakes abound it may be necessary to have an antivenom kit along and to know how to use it.

Photography. Certain types of ecological work depend upon general impressions as well as accurate observations in the field. Sketches may serve the purpose, but as a rule a picture taken with a camera may be as effective and is much quicker. Since most students are familiar with the use of a camera only a few special pointers for ecological work need be given here. The type of camera will depend upon individual preference, but in choosing a camera consideration should be given to size, weight (especially as an extra), ease of getting films, and utility of size in making lantern slides or for reproduction. In photographing vegetation, the exposure necessary is longer than in taking pictures of street

scenes. In photographing vegetation one seeks details, so he should take every advantage of opportunity to stop down as far as practicable and utilize a correspondingly greater amount of time for the exposure. When taking pictures of grassland, the best pictures are taken against the sun, but one must shade the lens so that the sun does not shine directly on it. For pictures inside of forests, the very best time is the early morning just before the sun has appeared above the horizon. For such photographs the layout is best determined the previous day. The early diffuse light penetrates beneath the canopy without causing shadows. Such conditions are very suitable for showing the general forest vegetation near the ground. Proper stopping and length of time, of course, need to be given. This can be learned by experience or obtained through the use of exposure meters. The resulting picture will be a great improvement upon pictures taken in the sunshine because of the lack of snowlike leaves which have reflected too much light into the camera and the dark jet spaces in which insufficient details can be recognized. Photographs may also be made of individual plants, both *in situ* and after they have been picked or dug and arranged. One of the most suitable backgrounds for many such plants is the tar-paper roofing which is often found in summer camps. Very white paper or cloth is objectionable, but often used, nevertheless. The jet-black background is often disadvantageous in reproducing the pictures by means of the photoengraving process. Plenty of light should reach the plant from various angles, so that no shadow will be visible. In general, for showing details of the parts a sketch or drawing is better than a photograph, but for showing masses of plants in the field, the photograph is much simpler. Photographs made at different intervals at the same place record data very quickly. If good notes have been taken in the first place so that a class in a later year may use them and take their own up-to-date pictures, good ecological comparisons may be made.

ASSOCIATION AND OTHER UNITS[1]

For an ecological study of vegetation, a certain amount of nomenclature is necessary. The fundamental unit is variously called *plant association, plant community*, or *plant type*. Standard definitions of these are as follows: An association may be defined as a relatively uniform area of vegetation in which the interrelationships of the component plants permit them to endure the physical environment. Or, according to Nichols: "Viewed *in the concrete*, a plant association may be defined as a plant community characterized by its essentially homogeneous physiognomy and ecological structure and by its essentially homogeneous floristic composition, at least with regard to dominant species. Viewed *in the abstract*, the association may be defined as a vegetation-unit characterized by an essentially constant floristic composition, at least with regard to dominant species."

Plant community is to be defined much the same except that occasionally a geographic boundary is assigned, which means that it might contain more or less than one association.

Plant type, used particularly by foresters, may express the equivalent of the association, or it may be a part of an association dominated by different groupings of dominant species.

The association, by one name or another, has been used for a long time as a satisfactory unit, but recently efforts have been made to limit its use to the final unit, the so-called *climatic climax*, and to use *associes* for the temporary or seral units leading up to it. This needlessly complicates a subject already burdened with terminology.

Formations. This term, formerly used much more than now, includes groups of associations which are characterized by having dominant ~~species of~~ essentially the same growth form.

[1] Cf. also Weaver, John E., and F. E. Clements, "Plant Ecology," 2d ed., pp. 89–105 in part, McGraw-Hill Book Company, Inc., New York. 1938; Braun-Blanquet, J., "Plant Sociology" (translated and revised by G. D. Fuller and H. S. Conard), pp. 21–25, McGraw-Hill Book Company, Inc., New York. 1932.

Provinces. The various associations and formations of a country may be assembled into provinces which are set off from one another by differences in environmental factors and plants. For instance, the deficient rainfall of the winter season combined with ample summer rainfall favoring grasses are the outstanding characteristics of the prairie province. The principal factors in the delimitation of provinces are the average temperatures through the year, the amount and distribution of rainfall, and in some cases the topography of the country and the plant covering. The climate, the soil, and the plant covering are interrelated quite closely.

Considering United States broadly, the following major provinces may be recognized: The Prairie Province in the center of the country is replaced to the eastward by forest provinces. In the northeast there is the Northeastern Coniferous Forest Province, with the eastern white pine, *Pinus strobus*, as one of its outstanding species. South from it is the extensive Central Deciduous Forest Province, with the sugar maple, *Acer saccharum*, as an outstanding species. Next comes the Southeastern Coniferous Forest Province, with the loblolly pine, *Pinus taeda*, as one of the outstanding species, followed in the southern part of the Florida peninsula and in the region of Brownsville, Texas, by the Subtropical Province. The region of Key West, Florida, is the only portion of the United States vegetated by a part of the Tropical Province.

In the eastern part of the Prairie Province one of the dominating grasses is the big bluestem, *Andropogon furcatus*, while in the western part the buffalograss, *Buchloe dactyloides*, is supreme.

West of the prairie is the Rocky Mountain Forest Province, which splits into two forks in northern United States. The eastern fork retains the name Rocky Mountain Province. The ponderosa or western yellow pine, *Pinus ponderosa*, is one of its outstanding species. The western fork going down the mountains in the Pacific Coast states is called the Pacific Coast Province. The sugar pine, *Pinus lambertiana*, is one of its important species.

Between these two mountain provinces lie two dry land areas. The northern portion, characterized by the sagebrush, *Artemisia*

tridentata, is spoken of as the Basin Province, while the southern part, extending down into Mexico, characterized by many types of cacti, is named the Sonoran Province.

Subdivisions of these provinces are recognized locally. It is most probable, however, that a beginning ecology class would not be working in vegetation belonging to more than one, at most two, provinces during a summer.

Within each province, unless the area is covered by the climax association, one finds series (seres) of associations, related successionally, leading towards the climax. To have succession[1] requires migration, in other words, the spread of the plants that are to bring about succession, together with their ecesis or establishment. If ecesis does not follow migration, succession cannot take place. When the succession reaches the stage in which under present natural conditions no other association will follow, that association is spoken of as the climax association. This really does not mean that it will last forever, for climatic changes do take place; however, so slowly that they are not discernible in a human lifetime. In addition, it does not mean that the climax association will come to occupy each spot. Many things prevent the tendency's finding full expression. In some cases associations filter into others, producing mixtures of greater or less extent. The term *mictium* is used. The border line between one association and another is spoken of as an *ecotone*. The characteristics of ecotones show up most sharply between forest and grassland associations.

Recognition of plant associations or plant communities. Only experience enables one to recognize plant associations and thus be able to tell whether a particular grouping should be spoken of as an association or a part of an association. In case of doubt, the various exercises indicated can be conducted and from the results a decision arrived at. For the person without experience there is a good deal of trial and error involved, but this need never interfere with taking up a definite area and conducting quadrat and tree counts on it. Once the idea is mastered, there is usually little difficulty in carrying on further work. In working with as-

[1] Cf. Weaver and Clements, *op. cit.*, Chaps. V–VII; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), parts of Chap. XIII.

sociations the determination of the dominant species is the first consideration (see Exercises 1, 2, and 13). All other species may be considered as secondary. Among the secondary species, however, some may be found which are dominant in other associations. Their position in a given area may then indicate invasion or they may be relics of the association previously occupying the ground. This gives four classes of species: dominant, secondary, invading, and relic. A fifth category includes species which occur in a wide variety of habitats and have so little to do with characterizing any that they are usually grouped by themselves as ubiquitous species. Several associations have more than one dominant species. If, in a given example, but a single dominant species is present, that example is considered a consocies, *e.g.*, the maple consocies of the maple-beech association. Associations also can be subdivided by the different appearance of parts, as tree, shrub, and ground layers in a forest or according to different aspects at different seasons of the year. Such groupings have been termed *synusia*, *i.e.*, a natural grouping of species of the same life form and with uniform ecological requirements.

More advanced students will find in the literature many additional terms used by various authors.

DIRECTIONS FOR EXERCISES IN PLANT ECOLOGY

QUADRAT METHOD[1]

Before starting work on the quadrat method, be sure to study over the section above entitled: Association and Other Units. Also, either previous to undertaking the first set of quadrat counts or shortly after taking the first set, study the exercise on life forms (Exercise 51).

The quadrat method, known also as the sample-plot method, is a basic method for many types of ecological investigation. It received the name "quadrat method" from the squares used as sample plots by F. E. Clements in 1898. The name "sample plot" is, however, the name used more commonly by agronomists and other workers, in both the plant and animal fields as well as in other types of statistical work.

The basic principle underlying the method is the saving of time and labor by selecting, in accordance with a prearranged plan, sufficient sample plots or quadrats to give data which will depart in no significant way from the data that would have been obtained if the complete area had been studied. The determination of the best size and the best number of sample plots is an exercise in itself but will need to be made for each type of work. In general classwork it is wiser to use three or four times the minimum number in order to smooth out irregularities due to the inexperience of students.

The quadrat, as usually used by ecologists, is a square area one meter on a side. As used by American foresters the quadrat is 6.6 by 6.6 feet, or $\frac{1}{1000}$ acre. Originally a square, as now used the shape may be quite variable; *e.g.*, in plant-disease survey work a circular hoop is employed. The size may vary from a square 10 centimeters on each side for moss and lichen studies to areas

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 10–33.

which may be 50 or more meters along the side in forest studies. Whatever the size or shape, the basic principle remains the same, *viz.*, to acquire pertinent data from small plots which are to represent the area as a whole.

Many students in working for the first time with the quadrat method feel that they are missing plants, especially conspicuous plants. Yet if such plants are important ecologically, other members of the class will find them in their quadrats. For such students it is often worth while to go back and forth over the area to try to find plants which have been missed in the quadrats. In work in the aspen association in northern Michigan, where from 30 to 50 kinds of plants are found in an area, species are rarely missed by a class taking 100 quadrats in the area. If one or two are missed, detailed study brings out that only one or two, or very few, specimens are present.

TYPES OF QUADRATS

Among the types of quadrats that may be used, the list quadrat stands foremost for ease in taking and for utility in introducing the subject.

LIST QUADRAT

Procedure. If a single individual is to take a series of list quadrats, it may be advantageous to run a string through the area to enable him to maintain a definite line or pattern. The line may form any pattern, such as an N shape or M shape, or simple straight line. If a class is to take list quadrats, they may be lined up along one side of the area at intervals that will vary with the size of the area. While single individuals may take a list quadrat, it is much more economical to have pairs of students do the work, one particularly to spot the plants, the other to record and maintain the direction. If it is essential that high mathematical accuracy be attained, the area should be laid off first, with the lines of travel accurately determined.

In starting a series in from a road, it is well to step in 2 to 3 meters from the edge, whether it is a grassland or forest area, to minimize or eliminate any effect that roads or trails may have. In northern Michigan studies have shown that the effect of a road

is reduced to less than 1 per cent within 3 meters from the road.

In setting up a list quadrat, stakes, surveyor's pins, or any convenient markers may be set at the four corners. In more important work it is advantageous to have two metersticks on rods hinged at the end with a strap to prevent their being opened more than 90 degrees. Three corners having been located, the rods may be turned 180 degrees and the fourth corner marked. During this setting up, the students should keep off the area to be studied.

The list quadrat, as its name implies, is a list of the names of the species present in the quadrat. It should include each and every species, whether the name is known or not. In the list quadrat, whether there are many or few examples of the same species makes no difference, a species is listed but once. The recorder keeps track of the species and of course helps in ferreting them out. When the plants in a quadrat are listed, the pair will proceed forward the stated distance, set up the next quadrat, and repeat the process. The simplest and most satisfactory form in which the data may be recorded is as follows:

Species	Quadrat number	Total quadrats
Plant *A*.........	1—3—9	(3)
Plant *B*.........	1—2—3—4—6—9—10	(7)
Plant *C*.........	2—6—8—10	(4)

Summing up the data is then simpler than if completely separate lists are made of each quadrat. If a good many species are found in the area, there are advantages in having the list made alphabetical. The number which is put after the species is the number of the quadrat taken. Any additional numbers separated from those ahead by a hyphen mean that species *A* was found in, say, the first, third, and ninth quadrats, etc. This makes it possible to separate the data by quadrats if that is necessary and it avoids the uncertainty that marks or crosses always engender. For instance, have you credited quadrat 3 with such and such a species? The number 3 would settle the question; an × might not. When the work is completed the number of quadrats in which each

species occurs will be written after the name of the species. This makes the determination of frequency a simple matter, since frequency is per cent. The frequency index where a species occurs in 10 out of 10 quadrats is 100; in 50 out of 100 quadrats, 50. It is seldom desirable to determine frequency closer than to whole per cents. Comparing the frequencies of plants in different areas is an important part of certain types of ecological work.

If the name of the species is not known, sufficient material should be put in a magazine or scrapbook and labeled the same as on the field notes (*e.g.*, "Unknown No. 1"). If identification cannot be made in the field, the plant should be carried on the records as unknown 1, 2, 3, etc. Thus it is possible to carry on list quadrat work without knowing the name of any of the plants by simply giving them some designation and preparing specimens which will permit identification by some authority later.

Assembling the Data. If a single individual is taking list quadrats, he has merely to count up the number of quadrats and express that number as the per cent of the whole number of quadrats taken. If, however, a class has taken the quadrats, the simplest procedure is to call the name of a plant, following which each group in turn adds on the number of quadrats in which they have found it; the final figure being the total number of quadrats in which the whole class found the plant, which is then expressed as the per cent of the total number of quadrats taken. If 100 quadrats are taken regularly, this simplifies the expression of frequency.

The species in a list-quadrat frequency count may be arranged in any order suitable for the purpose of the work. Common arrangements are systematic order by families, alphabetically, or by life forms.

Accompanying a set of list quadrats there should be notes regarding the general lay of the land, type of soil, slope, and various other features.

Before taking quadrats, one must consider the type of vegetation. In a forest the size of the quadrats for the tree count must be much larger than the size of the quadrats necessary for adequate expression of the frequency of ground plants. It is therefore convenient to divide the plants into "trees" and "ground plants" and use a different method for each. In general, trees

may be considered as woody plants 1 meter or more in height. The procedure with the trees will be explained later. However, if a tree occurs in a quadrat, list it with the ground plants. Woody plants under a meter in height are counted as ground species, as are the herbaceous plants. If special attention is to be given to the reproduction of trees, the tree species are listed in accordance with size or age. For instance, 1- or 2-year seedlings and small saplings approaching a meter in height can be recorded as separate units. For complete species frequency, however, these units must be added together.

Exercise 1. List Quadrats

Take 10 list quadrats according to the pattern in the area designated, after reading over the material above. The following form may be used in recording the data:

LIST QUADRAT

Group No............ Date..........
Location.............

Species	Quadrat number	Total quadrats	Frequency index
Plant *A*............	1—2—5—7—8—10	(6)	60
Plant *B*............	1—3—4—5—6—7—9	(7)	70
Plant *C*............	2—3—4—5	(4)	40
Plant *D*............	3—4—5—6—7—8—9	(7)	70
Plant *E*............	6	(1)	10

Be sure to accompany each table with data concerning the location and characteristics of the particular set.

NOTE: This exercise will be repeated many times in different parts of the same association and in different associations in the areas studied.

Count Quadrat[1]

To supplement frequency determination with a knowledge of the number of individuals of different species, count quadrats are taken. The procedure is to complete the list quadrat for each quadrat, following it immediately by the counting of the number of individual plants of each species. In recording it is con-

[1] Cf. also Weaver and Clements, *op. cit.*, p. 13, as list or census quadrat.

venient to use the number of the quadrat, the same as previously indicated in the list quadrat, and below or after the list number put in parentheses the number of individual plants, as shown below. The summation of the data is the same as in the list quadrat, yielding in each case the name of the plant, the number of quadrats in which it is found, followed by, in parentheses, the total number of individuals of that species found in the set.

The main difficulty in making count quadrats comes from the fact that several plants appear separate above ground but are really parts of a crown or rhizome system beneath the surface of the ground. While from one standpoint these could be counted as one plant, nevertheless, as the ecological action of the shoots above ground is that of individual plants, it is more satisfactory to count each shoot as an individual. An annotated list should make this point clear if the data are to be used for other purposes. The count quadrats call attention to the abundance, but still no distinction is made between fine plants and coarse plants, which simply indicates that the count quadrat is added information but not complete information. While it is possible to evaluate an approximation of cubic contents of the plant to use instead of simply presence, the labor involved is such that it is seldom done.

The second difficulty is in the evaluation of a clump. Although individual stems may be obviously a single plant, if the branching is just above the ground, the individual shoots may in reality act as individual plants. Whether to count the clump as one or to count the individual shoots as one each must be decided on the merits of the situation and the same system followed in the same piece of work and in studies with which comparisons are to be made.

Stump sprouts present similar difficulty. Obviously they are a single plant, yet by a more complete rotting of the stump the sprouts may become separated as individuals. Possibly a good method is to count only the thicker ones, *i.e.*, those whose crowns give them the chance to suppress the others by cutting off their light.

Exercise 2. Count Quadrats

On the areas designated, first take a list quadrat in the usual manner, recording the number of the quadrat in the set. Then

count the plants of each species and put the number in parentheses under the quadrat number, as shown below. Continue until all the quadrats are listed and counted. Use the following form to tabulate data:

COUNT QUADRAT

Group No........... Date..........
Location............

Species	Quadrat number (individual plants)	Total quadrats (total individuals)
Plant *A*..........	1 2 5 7 8 10 (4) (15) (1) (2) (10) (3)	6 (35)
Plant *B*..........	1 3 4 5 6 7 9 (2) (6) (8) (15) (1) (4) (4)	7 (39)
Plant *C*..........	2 3 4 5 (1) (2) (4) (1)	4 (8)
Plant *D*..........	3 4 5 6 7 8 9 (25) (10) (2) (20) (13) (14) (5)	7 (89)
Plant *E*..........	6 (9)	6 (9)

NOTE: Repeat as directed.

AREA LIST QUADRAT

Occasionally, especially in some agronomic work, it is desirable to know the area of the ground covered by each and every species. In such cases the area may be measured by setting up cross strings and counting the number of squares and major fractions occupied by the species in question. In areas of low vegetation the use of previously constructed frames with cross strings or wires will expedite the work in the field. Cardboard or celluloid squares of different sizes will aid in doing this charting.

Exercise 3. Area List Quadrats

Set up surveyor's pins 10 centimeters apart on each side of the square designated and connect with strings to form a checkerboard or place a frame with cross strings over the vegetation. For each plant count the number of squares and major fractions, as shown below, and record. Plants which occupy less than half

a square may be indicated together as less than 0.5 or recorded as shown in the diagram below (Fig. 1).

BASAL AREA[1]

Looking down at a quadrat, one often gets the impression that the ground is rather thoroughly covered; however, if clipped at the

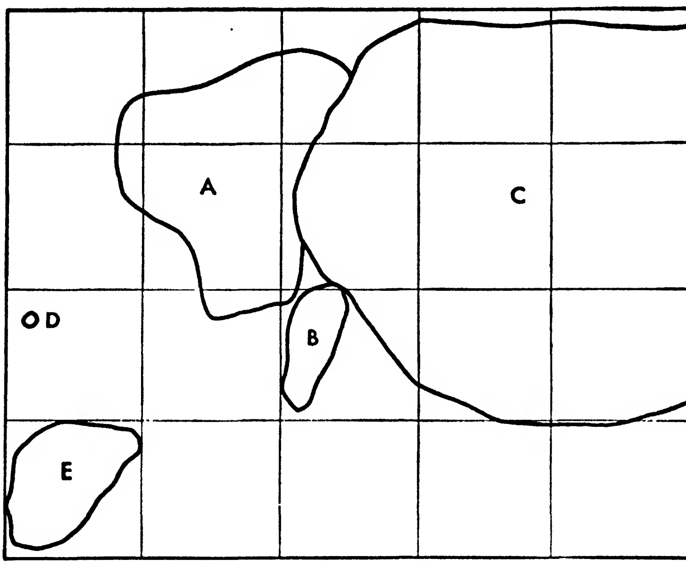

FIG. 1. A portion of a meter quadrat, the grid lines 10 centimeters apart, showing how to count the squares to obtain the approximate area. The units are 10-centimeter squares. *A* is recorded as 2 units; *B*, 0.4 unit; *C*, 7 units; *D*, 0.01 unit; and *E*, 1 unit.

ground level, it is seen at once that the plants emerging from the soil occupy but a small amount of the area. Determining the average area of the cross section of 50 or 100 or more stems of a species at the ground level and multiplying by the average number of stems of that species per square meter will give the basal area for that species. Figures for each species added together give the total basal area.

There are two principal methods employed: direct measurement of diameters within a measured area, or charting and measuring areas on the charts. In the first method, direct measure-

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 14–18.

ment may be made with a ruler graduated to millimeters or sixteenths of an inch. Better still, use calipers, small ones for the ground plants and tree calipers for trees. For cylindrical stems one measurement of diameter is ample, but, if not cylindrical, two or more measurements must be taken and averaged. With a knowledge of the average diameter the average area per stem may be calculated (πr^2, that is, 3.14 times the square of the radius) and this multiplied by the average number of stems in a unit area will give the basal area.

Plants in clumps present a problem. Should each stem be counted as an individual or should the whole clump be taken as one? Normally the area of the ground covered by a rosette, a bunch, or a hummock is measured from edge to edge, which does not settle whether the bunch is one or several plants. For such plants as *Festuca octoflora*, which grow individually in tight masses, the problem is very definite and different from a case such as *Carex leptalea*, where a clump 8 to 10 centimeters in diameter may have in it only a relatively small number of culms projecting into the air.

The data should include: the area of ground to be measured, the number of stems per unit of area, and the average area per stem. From these figures the percentage of ground occupied by the plants may be calculated.

In the second method it is necessary to chart, in detail, the stems and clumps at ground level in the area selected. Such charting is most conveniently done on cross-ruled paper after the area has been laid out in squares of convenient size (*e.g.*, 10-centimeter squares) with surveyor's pins and string. Charting may be done by penciling in the outlines of the various stems and clumps on the cross-ruled paper or by using a pantograph, if conditions permit the full sweep of the pantograph arms. Still another way is to photograph the area from directly overhead. From any such charts the actual area is determined by counting the number of small squares occupied by the stems or clumps, ignoring fractions of squares, if less than half a square is covered, and counting as full squares whenever more than half a square is covered. A planimeter may be used to trace around the outlines. When suitably calibrated, a direct reading of area is made. Still

another way is to cut out the outlines, as they have been drawn on paper, and weigh them on a delicate balance. Knowing the weight of a definite area of the same kind of paper permits making a calculation of the area occupied by the stems and clumps, in other words, the basal area.

The student will undoubtedly be impressed with the really small area of ground surface occupied by plants in what appears to be dense vegetation. This varies markedly from association to association in succession and may sometimes be used as an early indication that succession is under way. Determinations made in succeeding years may show unexpected changes in the density of the vegetation, even in the same area. (See page 237 in F. C. Gates, "The bogs of northern Lower Michigan," *Ecol. Monog.*, **12**: 213–254. 1942.)

Exercise 4. Basal Area

Lay out a quadrat and count the individual plants in it by species. With small calipers measure the diameter of 100 or more stems of each species in the quadrat at the ground and average by species. Find the area by the formula πr^2. If the stems are not circular in cross section measure sufficient diameters of each stem to give the diameter of an equivalent circle and proceed as above. Divide the area covered by the plants by the total area of the quadrat to obtain the percentage of ground occupied by plants, *i.e.*, the basal area.

Repeat, both in similar and in different habitats, using any of the methods mentioned above.

RECORDING QUADRATS BY PHOTOGRAPHY[1]

One of the quickest ways to record the appearance of an area is to take a photograph of it. Cameras may be set up directly above the center of the quadrat high enough to make it fill the film. A 6-foot folding stepladder may be used to support the camera as illustrated in Fig. 21 of Weaver and Clements. At the same time it is often wise to take at least one side view of the quadrat to help in the identification of the plants. If pictures and counting are done, the photograph should be taken immedi-

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 30–31.

ately after the quadrat is staked out and before disturbing the vegetation. Recognition of individual species of plants which closely resemble one another is likely to be impossible from photographs. However, for recording general appearance there is no better method.

Exercise 5. Recording Quadrats by Photography

Arrange a camera directly overhead and high enough from the ground to include all four corners of a quadrat. If shadows are objectionable, do this work in the shade, if possible, or on a cloudy day.

Supplement the overhead picture with exposures from one or more sides taken at an angle of 30 to 45 degrees with the ground.

PANTOGRAPH CHARTS[1]

If an area includes only low plants, as in the shortgrass plains, it is possible to set up a pantograph in the field and chart directly to scale the areas occupied by individual plants and clumps. The amount of reduction varies according to the set of the instrument. The pantograph is fastened near a corner of a drawing board which is set up next to the area to be charted in such a way that the encircling of plants by the pointer arm yields a similar, but smaller, penciled shape on the chart affixed to the drawing board in the proper position (Fig. 2). The usual 22-inch pantograph available in bookstores will reduce an area 50 by 50 centimeters to ⅕ that size conveniently. For research work larger sizes are desirable.

When all the plants in the area have been gone over, the field work is complete. The accuracy of the method makes statistical analysis possible and charts made at one time may be compared with subsequent charts of the same area, if the area is permanently marked.

The method requires somewhat cumbersome apparatus, good selection of area, and considerable time and close attention, so that but one or two may be done in a day. If there are plants sufficiently higher than the pantograph arm to interfere with its free movement, a pantograph cannot be used. For basal area

[1] Cf. Weaver and Clements, *op. cit.*, pp. 24–26.

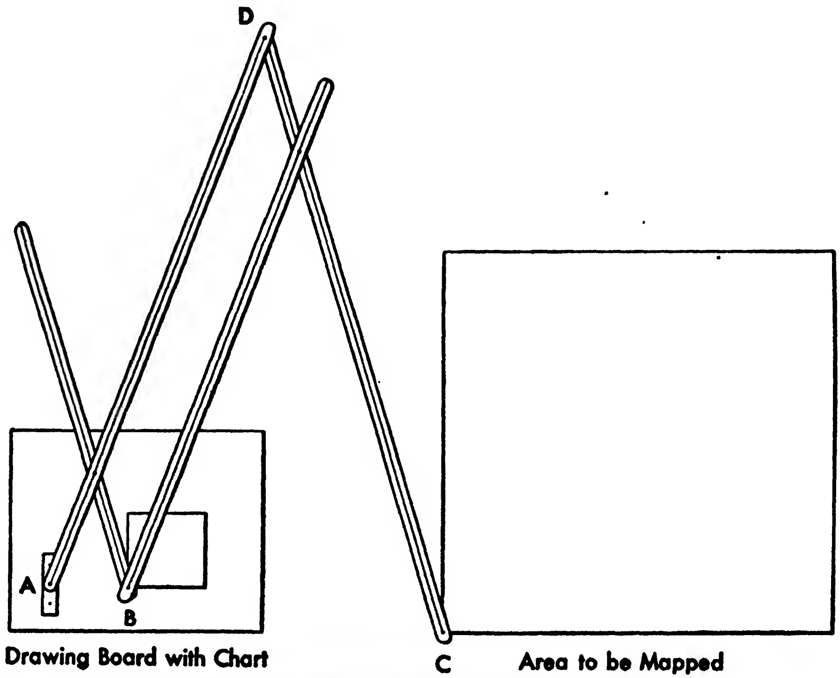

FIG. 2. (*Above*) A pantograph set to reduce to ⅕. To the left is a drawing board on pegs, firmly set up the proper distance from the area to be charted. On it is fastened the pivot *A* of the pantograph and the drawing paper. At *B* is the lead which marks on the chart; at *C* the pointer, now at the lower left corner of the area

work, especially after clipping, the pantograph can be used to good advantage.

The names of the plants drawn must be appended as soon as drawn. Conventional signs may be selected to represent certain of the commoner species. As always, north should be indicated.

Exercise 6. Charting by Pantograph

If opportunity presents, chart one or more quadrats by means of a pantograph set to reduce to ⅕, or other suitable reduction.

AREA QUADRATS BY SQUARES[1]

If a pantograph cannot be used, the area may be staked out in convenient units and strings run each way through the vegetation to form squares. Then the observer charts on cross-ruled paper as nearly as possible the extent and kinds of plants, square by square.

Exercise 7. Charting by Squares

Stake out an area with surveyor's pins and run strings through the vegetation to form 10-centimeter squares. Chart on cross-ruled paper each square in turn, using convenient conventional designations for the plants. NOTE: the first letter of the genus immediately followed by the first letter of the species is usually the simplest symbol to use. In studies in the prairie "Af" stands for *Andropogon furcatus* and "As" for *Andropogon scoparius*. Extra letters must be added to avoid confusion, however. For example, in northern bog studies "Cl" may stand for *Carex lasiocarpa*, but "Calc" for *Calamagrostis canadensis* and "Cali" for *Calamagrostis inexpansa*.

Repeat with other areas as often as desired.

ADDITIONAL CHARTING

Many different purposes may be envisioned for the use of charting procedure; *e.g.*, the area of a single type of species, or the location of seeds that are observed falling on an area; occurrence of seedlings, location of mosses, lichens, or plants of a certain color, or diseased plants, and other problems.

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 23–24.

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to be charted. Some support may be needed at *D*, the slider, to hold it off the ground and yet permit free movement as the pointer traces the outlines of the plants in the area being mapped. (*Below*) Making a pantograph chart on the college pasture at Hays, Kansas. (*Courtesy of F. W. Albertson.*)

POINT-OBSERVATION QUADRAT

For quick determination of the plant coverage of areas in connection with agronomic studies, particularly grazing, the point-observation method was developed by George Stewart and S. S. Hutchings (*Amer. Soc. Agron. Jour.*, **28**:714–722. 1936). While the method was developed in grassland areas, with certain modifications, as indicated later, it may also be used in forested areas. The materials used consist of nine surveyor's pins conspicuously colored, a ruler or string, and squares of cardboard or celluloid, 10 centimeters on a side. In this method the center pin is inserted a short distance into the ground at the first station and the eight pins are set along 45-degree angles, forming an octagon, which for practical purposes is essentially a circle. The radii may be varied but a radius of 0.565 meter yields a circular area of 1 square meter, or a radius of 0.80 meter yields an area of 2 square meters. The same setup is made at each subsequent station, the centers of which are located in accordance with a prearranged plan. In each area the plants should be noted first, or, as is commonly done, the plants are grouped in certain predetermined categories, depending upon the subject of the work. In grazing studies, the plants grazed may be divided into grazing grasses, palatable nongrasses, and weeds. In ecological work in northern Michigan we have arranged the groupings as follows: specially important species by themselves, the composites, other forbs, the grasses, the sedges—or the grasses and sedges—the mosses, and the lichens. When desired, additional categories are set up, such as seedlings of dominant species or of invading species.

Individual species may be used as well as groups of species, but the particular advantage of the method is that the less important species may be grouped so as to use less time in obtaining the data on the area. In actual operation, after the classification is set up, the observer uses the square cardboard by holding it over the vegetation and counting the number of times that that area will cover each category of the classification. The results are then expressed as units and tenths. When the data are assembled, division of the sums by the total area will express the coverage per square meter.

If a radius of 0.565 or 0.800 meter is used, then division by 1 square meter or 2 square meters, respectively, yields the coverage per square meter. For grassland areas this yields coverage which may then be compared to basal area to determine how much spreading has taken place. For instance, the basal area at the ground of *Festuca octoflora* and one plant of *Buchloë dactyloides* may be the same, but the amount of coverage of the buffalograss plant is much greater than that of the Festuca.

Exercise 8. Point-observation Quadrats

Set up a point-observation quadrat by putting in a center pin and eight pins, each 80 centimeters from the center on radii 45 degrees apart. Select suitable categories of plants. Taking each category in turn, using the square cardboard (10 centimeters on a side) hold the card over the vegetation, counting the number of times the area of the card will go into the area of that category of vegetation and record. To check the visual record, clip off the plants of one category and gently hunch them together on the card. It takes a little practice to make duplicate observations check. Divide results by 2 to obtain the coverage per square meter.

FOREST MODIFICATION OF THE POINT-OBSERVATION METHOD

In my use of this method in forested areas in northern Michigan it was necessary to modify the method on account of the varying heights of the plants. Customarily, layers or stories were selected and each story was considered as an integral point-observation quadrat. The layers most frequently used were: the high trees, which in a dense forest would give complete coverage; medium or small trees, if necessary; high shrubs; medium shrubs; occasionally low shrubs; herbaceous levels, especially at about a meter in height in areas in which *Pteridium latiusculum* (*Pteris aquilina*) was abundant at the Pteridium level; a ground level just above the ground; and, if necessary, the actual ground, in case it was not bare. As many of these different stories or levels were selected in each case as seemed necessary and the categories of plants were varied as the occasion demanded.

Exercise 9. Forest Modification of the Point-observation Method

Use the same sort of setup as in Exercise 8. Establish the categories in each of the levels desired and follow the same procedure for each of the categories in each of the levels.

A sample of data follows:

POINT-OBSERVATION DATA

Aspens, East of Gorge, Douglas Lake, Michigan, July 3, 1940, Ecology Class. (The recorded values are one-half the number of units observed, therefore giving the percentage coverage per square meter.)

Categories selected	Point-observation quadrat										Percentage coverage
	I	II	III	IV	V	VI	VII	VIII	IX	X	
Tree level	0	96	25	0	34	50	25	0	0	17	24.7
Pinus resinosa	....	....	(25)	....	(20)	(50)	(25)				
Populus grandidentata	....	(96)	....	....	(14)	....	....	....	....	(17)	
High shrub level	0	0	0	0	0	0	18	2.2	0	0	10.1
Pteridium level	41	22	24	32	33	64	56	22	20.3	38	35.2
Pteridium latiusculum	(34)	(22)	(24)	(32)	(33)	(64)	(56)	(22)	(14)	(38)	
Populus grandidentata	(6)										
Aster laevis	(1)										
Rhus glabra borealis	....	....	....	....	....	....	....	....	(2)		
Vaccinium pennsylvanicum	....	....	....	....	....	....	....	....	(4.3)		
Low shrub level	0	2	0	0	0	12	1.3	0.9	0.4	0	1.7
V. pennsylvanicum	....	(2)	....	....	....	(12)	(1.3)	(0.9)	(0.4)		
Ground level	0.9	27.6	24.8	13.8	6.7	19.4	5	18.5	52.2	89.5	25.8
Grasses (Oryzopsis, Danthonia, *Panicum meridionale*)	(0.8)	(17)	(8)	(7)	....	....	(2)	(2)	(1)	(6)	
Composites	....	(6)	(1)	(6)	(6)	(14)	(2)	(0.9)	(2.3)	(2)	
Vaccinium pennsylvanicum	....	(1)	....	....	....	(2)					
Stems											
Pteridium latiusculum	(0.1)	(0.1)	(1.4)	(0.8)	(0.7)	(1.6)	(1)	(0.3)	(0.1)	(0.5)	
Populus grandidentata	....	(0.5)									
Pinus resinosa	....	....	(0.4)								
Mosses	....	(3)	(14)	....	....	(1.8)	....	(5.3)	(47)	(80)	
Lichens	....	....	....	....	....	....	....	(10)	(1.8)	(1)	
Stump	....	....	....	....	....	....	....	(22)*			

*Not counted as living coverage.

PERMANENT QUADRATS[1]

Where long-time studies are desired, it is necessary to locate permanent quadrats. The usual method is to mark by driven stakes, preferably with iron pipe, the four corners of the quadrat area. The stakes should be long enough so that there is no chance

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 26–29.

of their being withdrawn accidentally. Whenever a count is made, any of the methods may be employed. Such permanent quadrats may be located anywhere with or without any special protection. It may be advisable, particularly if the permanent quadrat is located in a place likely to be disturbed, to fence off an area around the permanent quadrat. Normally permanent quadrats are exposed to whatever agencies are operating in an area.

Exercise 10. Permanent Quadrats

If opportunity presents, establish one or more permanent quadrats, as indicated above, or record the data from one or more which have already been established. Use any of the methods which have been presented, such as list quadrat, count quadrat, charting by squares, photographing, or charting by pantograph.

DENUDED QUADRATS[1]

In order to study the details of revegetation following the removal of vegetation, a permanent quadrat may be set up and the vegetation removed by burning, flooding, salting, covering, or by excavating the top 1 to 6 inches of the ground. Such quadrats may be started at different times of the year to bring out differences for which the season of initiation might modify the results which follow.

Actual revegetation may be obtained naturally (*i.e.*, without human interference) as seeds or disseminules get into the area from the surroundings, or in other experiments the normal revegetation may be modified by sowing seeds, planting parts, selective weeding, or by different types of fertilizer treatment.

Exercise 11. Denuded Quadrats

If time permits and there is opportunity, denude in various ways the vegetation from certain permanent quadrats and observe the results in the following weeks and years.

CLIP QUADRATS[2]

In order to simulate grazing or to ascertain the amount of vegetable matter produced, the vegetation from a square meter

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 29–30.

[2] Cf. Weaver and Clements, *op. cit.*, pp. 18–21.

is clipped off. The clipping may be done at the ground level or at various heights above it, depending on the purpose of the work. The clipped material is dried in the oven at a temperature from 100 to 105°C in order to obtain the amount of dry matter developed by the plants in the selected area. Results may be obtained for individual species of plants as well as the whole mass of vegetation. More than one clipping during the year will have to be made.

Although such clipping is not exactly equivalent to grazing, it is a useful method by which to obtain the yields of plant material and thus make comparisons between areas possible.

Exercise 12. Clip Quadrats

If feasible, obtain the ovendry weight of the forage clipped from designated square meters of ground in accordance with the suggestions above.

TREE COUNT

In forested areas it is customary to count the trees separately from the ground plants. The distinction is arbitrary, a common one being that all woody plants more than a meter high are included in the tree count. If the woody plants are shrubs, the assembled data are divided accordingly, as will be seen later.

SIMPLE TREE COUNT FOR FREQUENCY

The simplest tree count is the counting of some unit number, say the first 100 or 200 trees as one comes to them. This may be done by projecting a straight line through a wood, by helter-skelter movement, or by any special pattern desired. The advantages are that no account need be taken of area or direction, nor of exact size. Among the disadvantages is the fact that the area occupied by the unit number of trees may be quite variable in different sets. This might interfere with an accurate determination of the frequency and does make comparisons between different areas less significant.

Exercise 13. Tree Count

Following a path decided upon (straight line, inverted V, circle, or other pattern), name and count the trees that are within

a meter on each side of the path, until a prearranged number has been counted. If half or more of the trunk at the ground falls within the strip, such a tree should be counted. If there are not that many trees available, count all that are present and use the total number in calculating the percentage. Record as follows:

Species	Number*	Totals
Acer saccharum....	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 ///	53
Betula lutea.......	𝍸 //	7
Fagus grandifolia..	𝍸 𝍸 𝍸 𝍸 /	21
Fraxinus americana	𝍸 𝍸 //	12
Ostrya virginiana..	//	2
Tilia americana ...	𝍸	5
Total..........		100

* Since 100 trees were counted the numbers of each are also the percentage frequency.

Exercise 14. Tree Count with Diameter Classes

Repeat Exercise 13, but record the trees by diameter classes as shown below.

Species	Diameter class, cm	Number	Totals	
Acer saccharum............	0–10	𝍸 𝍸 𝍸 𝍸	20	
	11–20	𝍸 /	6	
	21–30	///	3	
	31–40	𝍸 𝍸	10	
	41–50	𝍸 𝍸 ////	14	53
Betula lutea...............	21–30	////	4	
	31–40	///	3	7
Fagus grandifolia..........	11–20	//	2	
	21–30	𝍸 //	7	
	31–40	𝍸 𝍸 //	12	21
Fraxinus americana........	0–10	𝍸 //	7	
	11–20	𝍸	5	12
Ostrya virginiana..........	0–10	//	2	2
Tilia americana...........	31–40	𝍸	5	5
Total.................				100

The diameters may be estimated by placing a measuring stick in front of the tree and standing off a little distance, or more easily

by using tree calipers. Since the diameter equals the circumference divided by π, a tape may be graduated to read diameters by marking off multiples of 3.14 for each linear unit of diameter. The following table shows the graduations for the first ten units, inches if inches are used, or centimeters if the metric system is used.

Units Diameter	Units Circumference	Units Diameter	Units Circumference
1	3.14	6	18.85
2	6.28	7	21.99
3	9.42	8	25.13
4	12.57	9	28.27
5	15.71	10	31.42

AREA TREE COUNTS OR TREE QUADRATS

Counting all of the trees in a definite area is a standard procedure in small forests, while in a larger forest definite quadrats may be set up. By dividing the number of each diameter class of each species by the total number of trees counted, one obtains the frequency. The size of the area may be varied, depending upon the type of forest. The area is always larger than that employed for ground plants since trees do not mature so close together. A quadrat 10 meters on a side has been found convenient in temperate regions, although local conditions may make some other size more useful. In many studies the figures are expressed on the basis of certain unit areas as per hectare, per acre, per tenth acre, or other unit. A very common practice, particularly in forestry, is to use areas 66 feet long and 66 feet wide (equals $\frac{1}{10}$ acre) in which the height, diameter, and the kind of trees are all taken.

Where statistical studies are planned, any definite area may be charted in accordance with the following simple procedure: the area on the ground having been laid out, strings or small ropes at suitable intervals are run through the area. A team of two students charts on cross-ruled paper the exact location of each tree, giving the name and diameter. Such areas are recharted at later periods to show the history of the area. Meter quadrats may be located within these areas to record the ground plants as well.

Exercise 15. Area Tree Counts

Stake out definite areas and locate squares as in Exercise 7. Count by species, species classes, or on cross-ruled paper chart the trees by name and class.

SPECIAL-PURPOSE TREE COUNTS

When it is desirable to know the frequency of some particular tree, a tree count may take cognizance of that particular species and lump all the others under such a designation as "other trees." The same method may be used for the presence of seedlings of trees.

Other uses suggest themselves.

TREE COUNT DONE BY STUDENT CLASSES

When classes of students take tree counts, the simplest procedure is to line up the members of the class on one side of the area and give each definite directions as to which way and how far to proceed in his count. Groups of two are most satisfactory, the lead one counting and naming the trees as he proceeds forward, the second person remaining on the spot as long as possible to record trees and distance and maintain correct direction. Before the lead person is lost sight of, he should stand still until the recorder comes up to him and checks direction ahead. In such counts both the number and kinds of trees as well as the diameter classes may be taken. A simple means of maintaining a proper strip in case one doesn't wish actually to lay down strings in the landscape is to use two metersticks, which are held by the lead person horizontally at meter height, one stick in each hand. As he proceeds, any tree touched by either stick is counted, and since the two sticks are not fastened together, it is possible to go through a forest without much difficulty.

The primary purpose of the tree count is likely to be threefold: (1) the kinds, *i.e.*, the species represented, (2) the numbers, and (3) the sizes. The sizes of the trees include the height and the diameters breast high (DBH), *i.e.*, 4.5 feet above the surface of the ground. Height may be expressed in actual figures but is much more likely to be divided into such categories as seedlings,

small saplings less than 2 meters high, between 2 and 7, between 7 and 10, between 10 and 30, and above 30 meters. These are almost always estimated, although if down trees are present they may be measured directly, or if a hypsometer is available, it may be sighted to give the height of the tree. Likewise, if it is not possible to get the shadow of the tree, one can take advantage of the fact that the tangent of an angle of 45 degrees is unity, as shown in the diagram (Fig. 3). Locate a 45-degree triangle on the ground

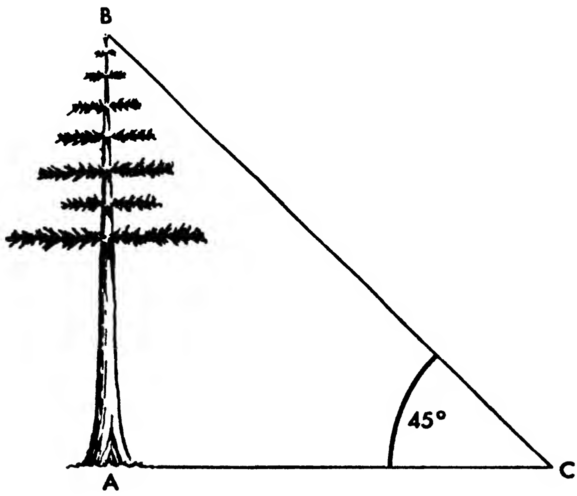


FIG. 3. How to find the height of a tree. *CA* equals *BA*, when the angle *ACB* is 45 degrees.

so that its hypotenuse projected will hit the top of the tree. The distance of the ground point from the base of the tree (*CA*) is the height of the tree (*AB*). The diameter, which is taken breast high and expressed as DBH, may be taken directly to the nearest inch or centimeter but in general is taken within certain classes. A little experience enables one to estimate it quickly, but doubtful cases had best be measured with tree calipers. Trees which are not cylindrical will require such measures at right angles to each other, the figure recorded being the average. The usual classes measured include saplings which are under an inch (2.5 centimeters) in diameter, then 1 to 2 inches (2.5 to 5 centimeters), 2 to 4 (5 to 10), 4 to 8 (10 to 20), and continued in multiples of 4 inches or 10 centimeters. Notations regarding any

observation or determinable facts about trees may be made on the spot and included in an annotated list.

When the class has finished taking the tree count, the figures should be grouped together to give the percentage of trees of each species in the classes of height and diameter for given areas. Tree counts taken in this manner are ready to be used in vegetation formulas.

Exercise 16. Class Tree Counts

Following the directions given above, groups of students will make tree counts in prearranged lanes in a given area and assemble the results into one table.

NOTE: For the average class in field ecology the usual field procedure in studying any forested area will include a tree count by one or more of the procedures mentioned above, by each team. The data of all the teams will be assembled to show at least the number and percentage of each of the various kinds of trees on the area selected. The data may be in the form of tables or they may be accompanied by charts or diagrams. On the same area a suitable number of ground-plant quadrats will also be taken and tabulations made of the frequency of the species found. Such studies will be supplemented by data on such other items as: soil, physiography, drainage, hydrogen-ion concentration, climatic conditions, local factors—all aimed to present an adequate portrayal of the area studied.

Thus by combining one or more of the quadrat methods with one or more of the tree-count methods, studies of several plant communities or of several examples of an association may be conducted through a summer to gain an insight into the vegetation of a region.

OTHER METHODS OF DETERMINING FREQUENCY

THE STRING METHOD

A piece of string or twine may be stretched between two stakes just above the ground vegetation. Plants whose crowns come immediately under or over the string are then counted and the frequency determined by dividing the number of each species by the total number of plants counted. This may be varied to include an area between two strings stretched, say, 10 centimeters apart.

Exercise 17. Determining Frequency by the String Method

By following the directions suggested above determine the frequency of various plants by the string method.

NOTE: If instead of merely noting the presence of plants along the line or within a short distance from it the thickness of the plants is measured, this method becomes the line-interception method (page 36) and yields both frequency and density in addition to position along the line.

If the plants at the line are recorded by name in order of occurrence, it becomes a transect (page 43).

LINE-INTERCEPTION METHOD OF SAMPLING VEGETATION

(Modified slightly from Canfield)[1]

In this method advantage is taken of the fact that, for a given area, rectangular plots longer than wide give a better sampling than square quadrats. The line carries this idea to the possible limit. The bearing and the location of the ends of the line for samplings are set up in accordance with a prearranged plan to obtain random samples. The line is stretched and staked firmly in position in the area under consideration. The line is considered to have indefinite length and vertical extension, but lateral width is limited to 5 millimeters on either side, although it is better to use 10 millimeters on one side.

For simple frequency, each plant that is intercepted by the line is recorded according to species. The number of times the species is intercepted divided by the number of plant interceptions is the frequency. This is usually expressed as a percentage.

To measure the density of the vegetation, as each plant is met (intercepted by the line) the name and the diameter on the line are recorded. The measurement includes only the intercept of the vegetation encountered, as shown in Fig. 4. Shrubs may be measured both at the surface of the ground, if intercepted, and at the diameter of the crown in the vertical plane above the line (crown intercept). The same plan will need to be used if a tree layer is present.

[1] CANFIELD, R. H., "Application of the line-interception method in sampling range vegetation," *Jour. Forestry*, **39**:388–394. 1941.

The assembled data will show for each species — or each group, if certain species are grouped — the total linear extent intercepted by the line in appropriate units. Dividing this by the

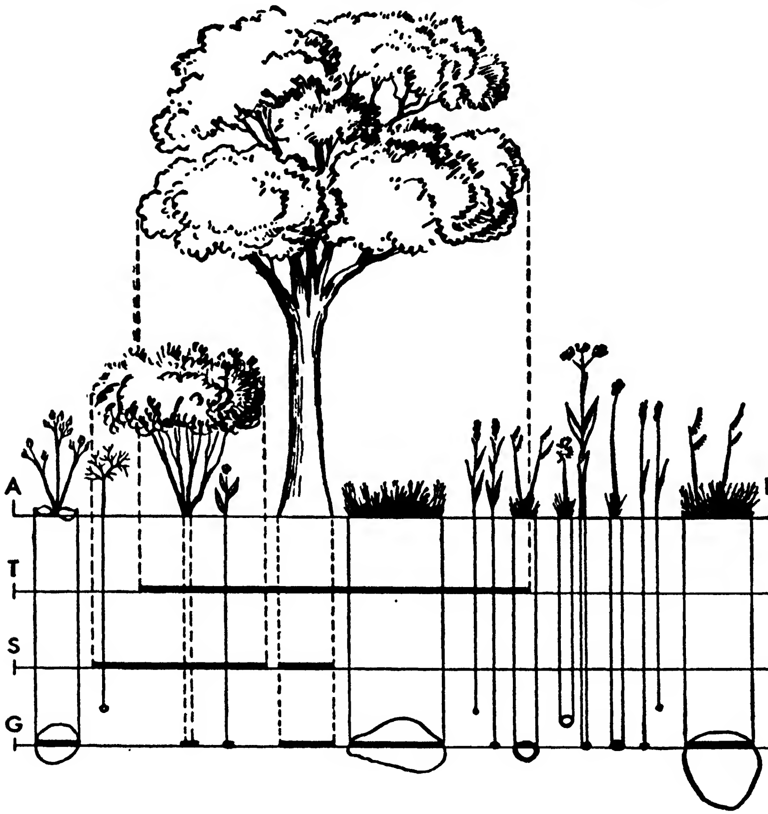


FIG. 4. Side view of a line in the line-interception method, showing the plants at or within a short distance of the line AB. Below, in three levels (T, tree; S, shrub; and G, ground) are the projections, heavy lines showing the part to measure in each level. NOTE: four plants that show in the side view but are not within 1 centimeter of the line are not to be measured. The trunk of the tree, which happens to be on the line, is measured as a transgressive in both the shrub and ground layers. Only the parts of clumps or patches of ground plants that are within 1 centimeter of the line are measured, irrespective of the total extent of the patch.

length of the sampling unit and multiplying by 100 gives the percentage of ground occupied. Dividing the length for each species or species group by the total length of that level of plants and multiplying by 100 gives the percentage composition.

This method has a variety of uses but has been used most

expeditiously in grassland work to measure composition, density, forage utilization, and forage volume. It has the advantage of simplicity in training crews for work both in the field and in the office.

Exercise 18. Line-interception Method

Set up a plan for locating lines along which to take the data. If but a single area is to be studied, space starting points along a line about 3 meters in from one edge and lay out parallel lines at right angles to the starting line. The length of the lines may depend upon how many there are, but 15 meters or 50 feet is quite satisfactory. Experience indicates that twice as much length is necessary to give a fair sample if the density is below 3 per cent than if it is above 5 per cent. If several areas are to be sampled, set up the same arrangement of lines in each and make them the same length.

Procedure: From the starting point proceed along the line, recording the width of the stem or clump at the ground for each herbaceous plant within 10 millimeters of the line and the intercept of the upright plane with the crown of each shrub or tree. Each species may be treated individually, or if only certain ones are vital to the study, others may be grouped in various fashions; *e.g.*, if a lawn were being studied the weeds could all be grouped together.

After the field data have been gathered, they should be assembled by teams for the whole class. From the total length measured, the percentage of the line occupied by the different plants as well as the different types of vegetation can be calculated.

SAMPLE OF DATA BY INDIVIDUAL GROUP

Group No. ...1... *Date* ...July 7, 1947... *Elapsed time* ...65 min....

Place ...Aspens east of the Gorge...

Length of strip in mm ...30 meters... *Width of strip* ...10 mm....

Species	Occurrences (expressed as length of each in millimeters)	Totals
Plant *A*.............	15, 20, 10, 13, 12	5 (70 mm)
Plant *B*.............	2, 1, 3	3 (6)
Plant *C*.............	3, 5, 40	3 (48)
Plant *D*.............	7, 10, 17, 9, 17, 20, 14	7 (94)
		18 (218)

SUMMARY OF CLASS DATA

Species	Group	Occurrences	Length, in mm	Totals
Plant *A*	I	5	(70)	241 (2327)*
	II	78	(507)	
	III	45	(420)	
	IV	113	(1330)	
Plant *B*	I	3	(6)	98 (104)
	II	78	(90)	
	III	...	....	
	IV	4	(8)	
Plant *C*	I	3	(48)	6 (85)
	II	...	....	
	III	3	(37)	
	IV	...	....	
Plant *D*	I	7	(94)	118 (1024)
	II	45	(340)	
	III	52	(390)	
	IV	14	(200)	
Length of strip, in mm	I		30,000	122,000
	II		30,000	
	III		33,000	
	IV		29,000	

* To obtain the length in meters, multiply by 0.001.

To obtain the area of the strip in square meters, multiply the length in meters by 0.01, since the strip is 1 cm wide.

To obtain coverage, divide the length obtained for each plant by the total length of the strips.

To obtain frequency, divide the number of occurrences of a given plant by the total occurrences of all plants.

THE METHOD OF SQUARES BY USE OF A FRAME

A framework 1 meter long by 1 meter wide, subdivided into 10-centimeter squares, may be made of wood and twine or wire and set down over the vegetation at selected spots. The presence of each species in the various squares is then determined. Dividing the number of squares in which a plant was present by the total number of squares (100) gives the frequency. This method may help in taking count quadrats but is more laborious than taking list quadrats. The vegetation must be low and without shrubs and trees, to permit its use.

Exercise 19. Frequency by the Method of Squares by Use of a Frame

Make a framework 1 meter square with strings or wires strung each way at 10-centimeter intervals. Place it over vegetation at

designated spots. Determine the presence of the various species in each square. Divide the number of squares in which each species occurs by the total number of squares (100) to obtain the frequency for each species.

Circular hoops or other shapes may be employed. Such a hoop thrown from place to place in grain fields is used to determine disease frequency. A count of the diseased plants within the hoop in comparison with the total number of plants within the hoop gives the disease frequency.

PERCENTAGE AREA FREQUENCY

A frame of squares is laid over the vegetation and the area that each plant occupies in each square is estimated and added together and divided by the total area.

Exercise 20. Percentage Area Frequency

Use a frame of squares, as directed above, to determine the area frequency of the various plants in the area under consideration.

POINT-QUADRAT METHOD

A method of determining frequency by obtaining statistical data in accordance with a plan which will not vary with different operators was developed by Fred W. Tinney, O. S. Aamodt, and Henry L. Ahlgren in a "Preliminary report of a study on methods used in botanical analyses of pasture swards" (*Amer. Soc. Agron. Jour.*, **29**:835–840. 1937).

A framework, 1 foot high or more, is built as shown in Fig. 5. Wire pins about 14 inches long are put through sets of holes which are 2 inches apart. In operation the frame is set down over the vegetation and the pins pushed down until they touch the plants. In one method the worker records only the first plant which is touched by a pin. In a second method the pin is pushed on and on until it hits the ground, scoring for each plant touched. After completing the scoring of the first pin, the second is pushed down and so on. This apparatus may be built or set so that the pins form an angle with the ground. An angle of 45 degrees with the ground is perhaps the best to employ. Photographs of either may be taken.

Instead of movable pins the framework may be built with fixed wires from top to bottom. In use this frame is held at a 45-degree angle from the ground. The plants which touch the wires are counted.

Exercise 21. Point-quadrat Method of Determining Frequency

Set up the apparatus figured below along a line through vegetation. Score the "hits" made by the points on the different

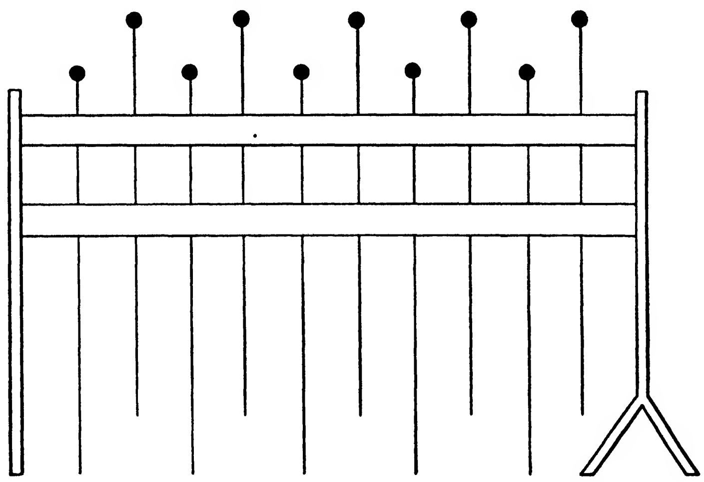


FIG. 5. Apparatus for taking point quadrats (explanation in the text). A pair of side arms may be provided to tilt the frame 45 degrees.

plants. The "hits" recorded for each species divided by the total number of hits of vegetation by the pin points used gives the frequency.

COMMUNITY COEFFICIENT

In order to make statistical comparisons between parts of a given area, or between different areas or associations, community coefficients have been developed. Community coefficients are simply numbers expressing resemblance. As originally developed by Jaccard, the numbers, according to American experience, seemed too low. Consequently an adaptation was made by Gleason. He used the frequency index instead of just the occurrence and obtained what we shall call the FICC (frequency index commu-

nity coefficient). The basic method of obtaining the coefficient is the same in either case, but in Jaccard's system a number 1 is used for each species concerned, while in Gleason's plan the previously determined frequency index is used in dealing with each species.[1] This gives greater weight to species more frequently found.

To compare two areas, set up three columns. In the first put the frequency of each species that occurs in the first area only; in the third column the frequency of the species that occur in the second area being compared only, while in the second column put both frequencies of species that occur in both areas 1 and 2. Add all the columns and divide the central column, which contains the data for the species common to the two areas under comparison, by 2. To obtain the coefficient divide the number thus obtained (column 2 total divided by 2) by the total obtained by adding this number to the addition of the total of columns 1 and 3 and multiply by 100, as shown in the table in the exercise following.

The coefficients obtained by the Gleason method yield relatively high figures, usually in excess of 80, if the two areas are in the same association in the same region. Still one may find areas close together, appearing similar to the eye, which do not yield coefficients in excess of 60. The method is open to the criticism that no distinction is made between a species which occurs in small numbers in a quadrat and one which occurs in large numbers. However, experience has shown that the approximation is useful at least in beginning work.

Pictures may be taken of different quadrats to facilitate comparison, but pictures fail to yield a number which can be used statistically.

Exercise 22. Frequency Index Community Coefficients

First determine the frequency indexes of the plants of two or more areas.

Using the figures for FI thus obtained, fill in a table in the following manner:

[1] GLEASON, H. A., "Some applications of the quadrat method," *Torrey Bot. Club Bul.*, **47**: 21–33. 1920.

To Compare the Plants of Two Areas

Species	Frequency by area or set			Species	Frequency by area or set		
	I	Common (I + II)	II		III	Common (III + IV)	IV
Plant *A*.	6			Plant *A*. . . .	15		
Plant *B*.	. .	3, 4		Plant *B*. . . .	35		
Plant *C*.	5			Plant *C*. . . .	. . .	. . . .	17
Plant *D*.	. .	15, 35		Plant *D*. . . .	56		
Plant *E*.	. .	. . . . . .	8	Plant *E*. . . .	64		
Plant *F*.	. .	20, 20		Plant *F*. . . .	. . .	. . . .	57
Plant *G*.	. .	30, 6		Plant *G*. . . .	. . .	. . . .	75
Plant *H*.	2			Plant *H*. . . .	35		
Plant *I*.	. .	. . . . . .	1	Plant *I*.	. . .	2, 2	
Plant *J*.	. .	60, 75		Plant *J*. . . .	. . .	. . . .	80
Totals.	13	268	9	Totals. . . .	205	4	229
½ of Common = 134 ½ of Common + I + II = 156 FICC = $\frac{134}{156} \times 100 = 86$				½ of Common = 2 ½ of Common + III + IV = 436 FICC = $\frac{2}{436} \times 100 = 0.5$			

Areas I and II are quite similar, in fact, the same association. Areas III and IV are dissimilar, *i.e.*, two different associations.

Compare various areas as directed above—not only areas which are obviously similar, but also areas which are quite different.

TRANSECTS[1]

Transects may be defined as lines through vegetation. In early ecological work they usually extended across two or more types of vegetation and were particularly valuable in that they showed where the change from one type of vegetation to another occurred. More recently it has been shown that rectangular quadrats or sample plots longer than wide give better results than square quadrats. The limit to which this can be carried is a line. (See The Line-interception Method, page 36.)

Transects may therefore be used to determine composition, frequency, and density within an association, a plot of ground, or larger areas, and also to show changes from one type of vegetation to another.

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 33–39.

There are three common types of transects:

1. The line transect is a cross section of vegetation in which a line is established from one point to another by stretching a stout cord or wire between two stakes. All the plants which touch that line are recorded in the order in which they occur. A person reading over that list and knowing the plants concerned is aware of the change from one type of vegetation to another. If the line crosses bodies of water and if the profile is also given, a line transect shows these changes very well.

2. Instead of a line a belt transect may be made. The only difference is that an area of definite width, usually small—5 or 10 centimeters—is used and in this area the plants are listed. A list is made for each unit of area. It shows essentially the same facts as the line transect but is more cumbersome.

3. The associational transect is really a belt transect in which the association only is named instead of the individual plants. This is advantageous where the line crosses undulating ridges and swales. Although not difficult to take, it requires previous study of the vegetation and recognition of its types. For associational transects areas of various sizes may be used, such as the whole meter quadrat or an area a meter long and 10 centimeters wide; or half a meter long and 10 centimeters wide, varied to fit the particular case; or the actual width of each association the line or belt crosses may be noted. One student manipulates the string and sticks and recognizes the plants and the other member of the team maintains the direction and records the results. If the transect crosses water, however, and sticks are used, it usually requires three or four students to maintain the sticks in position while the transect is being taken.

The series of great belts around the world (equator, tropics, temperate and arctic zones) is really a transect on a grand scale.

Exercise 23. Line Transect

Stretch a stout cord between two stakes set some distance apart in different types of vegetation. Record in order the names of the plants touched by the string. When taken from a point in a lake or stream up onto the shore, the value of a transect is best shown. It is desirable to accompany the line with a profile

along it. This may be estimated or developed to scale. (For the latter see directions under Exercise 49, Surface Profile.)

Exercise 24. Belt Transect

Set up two parallel cords, 10 centimeters apart. Consider each 10-centimeter square as a unit. Make a list of the plants in each, unit by unit in order. Belt transects are also best accompanied by profiles.

NOTE: See also The Line-interception Method, page 36.

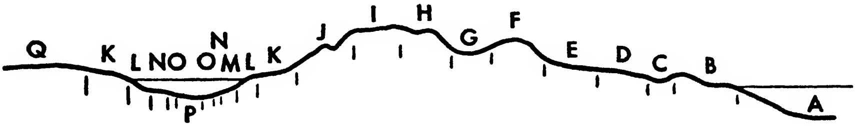


FIG. 6. A part of an associational transect taken west from Lake Michigan in the beach area, north of Waukegan, Illinois, in 1909. *A*, Lake Michigan; *B*, open sand of lower beach; *C*, beachpool with algae; *D*, open sand; *E*, Cakile-Xanthium association on middle beach; *F*, Salix dune with Calamovilfa; *G*, *Potentilla anserina* association; *H*, Salix dune with *Juniperus horizontalis; I*, *Andropogon scoparius* bunch-grass prairie; *J*, heath with blowout; *K*, *Scirpus americanus* association; *L*, *Scirpus validus* association; *M*, *Typha latifolia* association; *N*, Castalia-Nymphaea association; *O*, Potamogeton association; *P*, Little Dead River; *Q*, *Liatris spicata* prairie. Separations are indicated below the line of the profile.

Exercise 25. Associational Transects

Stretch a long stout cord between stakes in a line which may extend for a considerable distance. Record the associations crossed either in units of distances or by setting down the width of each association. If the first method is used, determine the outstanding association in each meter and record. In case more than one association is present in the meter it is necessary to decide which is more important to record, or to record both. Often a mixture must be recorded, *i.e.*, the transition from one association to another. In the second method of recording, measure the width of the association or mixture first encountered, record, proceed to measure the second vegetation type until another change is encountered, record, and continue (Fig. 6).

Each type of transect is best expressed on cross-ruled paper. It is always desirable to accompany it with a profile of the surface of the ground.

MAPPING

In many phases of ecological work it is necessary to use maps. Often the maps have to be made by the class itself. Several methods are available, some of which require expensive instruments, while by other methods maps may be made with the simplest of tools. Maps are necessary both as base maps on which to put data to show occurrence and distribution and also for comparative purposes. Since most ecological maps cover a relatively small area, the basic problem of having to select the right projection does not arise. Rectangular coordinates will serve all class purposes. Once a base map has been made, it is a simple matter to duplicate it by mimeograph and obtain as many copies as necessary. The habit of making and reading maps is a most desirable one, not only in ecology, but in any study in which geography is concerned.

TYPES OF MAPS

1. *Simple sketch.* Simple sketches may be made from any point of vantage from which one may see the various parts of an area and picture them as he sees them. One should, however, keep in mind that a distance between two points appears to be smaller when the observer is at a distance from them, than when he is close to them. Adjustment for this should be made as the sketch map is drawn. Good practice is for the same individual to sketch a given area—a pond or a lake for instance—from different points of vantage and compare the maps which he makes. The disadvantage of sketch maps is that although the scale on a map is usually considered the same throughout, the corresponding scale of the ground is likely to become shorter the greater the distance from the observer. Outlines that are closer to the observer are easier to draw correctly than those which are farther away from him, but if the distance is too great even the outlines cannot be well seen. In spite of their disadvantages, sketch maps are most useful in taking notes on small areas. Sketch maps may be made from photographs. The same disadvantages apply, unless one is skilled in rectifying the scale, as distance from the observer increases.

If a suitable base map has been provided, sketching in various details is very much simpler and more accurate than if the original observer makes both map and details at the same time.

2. *Triangulation with the distances measured.* Several methods of triangulation are in standard use in all types of surveying. In this method the only implements required are a tape or chain or measuring sticks and labeled stakes to mark the points. For this method it is desirable to go over the area to be mapped and put in stakes for the various points. Such stakes should be plainly visible from the others and are usually indicated by a flag or piece of cloth, colored or white, to make them more visible. In using this method one simply measures the distance from 1 to 2, 2 to 3, and 1 to 3, etc., as indicated on the diagram (Fig. 7*A*). This is continued so that there are always two measurements from each and every point. The data sheet simply states in column 1 the points, as 1 to 2; in column 2 the number of feet, meters, or whatever units are used; and in column 3 any remarks necessary. This procedure is followed until the points which have been set up are completed. If the area mapped by this method is compact, the points may be on or near the periphery. If the area is more extensive, as around a lake across which the tape will not reach, the series of triangulation points must be set up on land around the lake. The degree of accuracy on the finished map will be checked by noting how closely the end point coincides with the starting point.

The principal difficulties are in accurate and uniform stretching of the tape or chain if it is in the air or on uneven ground. Tapes in air always form a catenary, and the longer the distance, the deeper the catenary. If a spring is put on one end of the tape and stretched to the same figure, the results are a little better, but this is seldom done. If measuring sticks are used and they are simply laid on the ground, the inequalities of the ground often make the measurement off a foot or more in a distance of 60 or 70 feet. This can be corrected by putting in posts to maintain the measuring sticks level. The failure of having the tape or stick exactly on the zero point and the failure of sufficient accuracy in reading result in errors. Having two people make the reading as a check helps mitigate this. If a cloth tape is used, one must re-

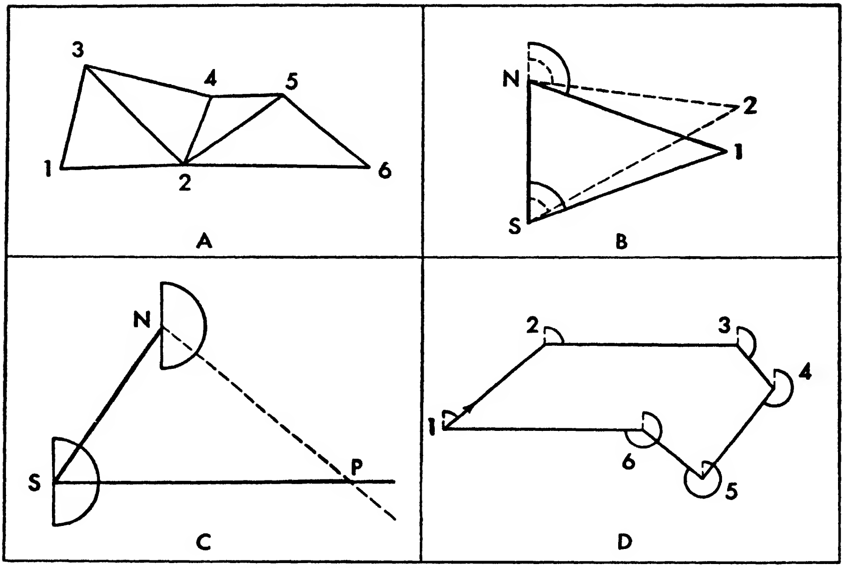


FIG. 7. Some principles of mapping.

A. Mapping with stations and tape. Data for this diagram are as follows:

Points	Distance, Ft	Points	Distance, Ft	Points	Distance, Ft
1–2	25	2–4	16	4–5	15
1–3	23	3–4	27	2–6	40
2–3	30	2–5	26.5	5–6	24

B. Roving-point method with base line north-south. The angles for point 1 (solid line) are from the north compass N 110°, from the south compass N 70°; for point 2 (dash line) from the north compass N 98°, from the south compass N 60°.

C. Setup for mapping when the base line is on a slant. Base line 50 feet long. At each end a protractor is oriented north-south. The white thread (dash line) is looped around the pin at the north end of the base line and stretched at the angle, N 130°; the black thread (solid line) is looped around the pin at the south end of the base line and stretched at an angle of N 90°. The intersection of these two lines is the location of the point *P*.

D. The traverse method. The data illustrated are as follows:

Points	Direction	Distance, Ft
1–2	N 50°	35
2–3	N 90°	50
3–4	N 140°	15
4–5	N 220°	30
5–6	N 310°	20
6–1	N 269°	52.5

member that it will shrink if it is allowed to get wet. Another objection is that in triangulating through a forest, if the original points have not been carefully located the lines may run through trees, which makes it necessary to take the tape around, thus introducing errors or necessitating the relocation of the points.

When using steel tape it is necessary to keep it from kinking. If wet, it should be dried and preferably oiled slightly before being put away.

With all the disadvantages, the main advantage is the simplicity of the method and the inexpensive tools which may be used.

3. *Triangulation, using a base line and flag stations.* This method of triangulation is suitable for rough country and across bodies of water. A definite base line of convenient length is set up and measured. Flag stations for the different key points are set out in the area. The flag stations must be visible from each end of the base line. (NOTE: If not visible from both ends, a second or subsidiary base line will have to be set up later to get the cross location of all such flag stations.) The base line should be on as high ground as possible. It must be measured with considerable accuracy. It is best located so that it will give large angle measurements to all parts of the area; in other words, to one side of the area. If it is located in the middle of an area, there will be points close to the projection of the base line on which it will be impossible to take data. In operation, a transit, a planetable (a drawing board set up on a tripod), or a compass is set up at one end of the base line. The observer sights to each flag station in turn, recording the number of the station, the angle, and any remarks that are necessary. If a transit is used, the angle is read on the compass and recorded, preferably from zero clockwise to 360 degrees. This means that after each sighting the compass needle must be allowed to come to rest and the reading made always clockwise from north to the flag station sighted. If a simple sighter is used instead of a regular transit, then it is necessary to set the planetable definitely by compass. Army planetable boards have a compass on the edge which permits orientation of the board. The north line should be indicated on the map and checked up during the progress of working as well as at the

end of the work. If a simple sighter is used on a planetable, lines may be drawn along the edge of the sighter to indicate the direction and numbered or lettered for the particular flag station, or the angle from the base line to the flag station is read on a protractor and expressed clockwise as an angle from the base line selected. These figures are recorded in the notebook against the number of the points. If distances are great, it may be nearly impossible to be absolutely certain of the number of the station. In such circumstances it is desirable to have a person or system of signals to relay information that may be needed by the observer. Occasionally on irregularities in shore lines the next point may really be back rather than forward and the observer at the base line may not be able to realize this. More careful selection of points would avoid this, but that would depend on the area and it may not be possible to obviate it. When one has finished reading all of the flag stations from one end of the base line, he moves the transit, sighter, or planetable to the other end of the base line, setting up exactly over it and repeating the whole performance. It is necessary to be certain that the observation is recorded correctly in accordance with the number of the flag station. When the field work is completed, one has either intersecting lines on a map or compass directions or angles from each end of the base line to each flag station. Lines may be drawn on the map on the planetable instead of recording angles.

In constructing the map from these data, one needs to estimate about the area covered in accordance with the scale used and lay off the base line. For class purposes 1 millimeter to 1 foot is a very handy unit to use. From each end of the base line in turn in accordance with the compass directions or the free angles from the base line, lines will be drawn. Where these two lines cross is the location of the flag station. If one has many points and does not want to draw a multiplicity of lines, a simple procedure is as follows:

Two people are required but three are better. At each end of the base line a pin is firmly stuck in the board. On the base line are set protractors, one at each end, so that angles can be read. The base of each protractor must be oriented to the proper compass direction. When the two protractors have been located and

fastened down with pins or thumbtacks, two different colored threads (white and black) are selected and a loop made in one end of each and looped over the pins at the end of the base line. Mapping may then proceed. The mapper reads the angle first for the white thread, whereupon the person who is managing the white thread stretches it taut so that the thread passes over the proper angle or direction on the protractor. Holding the thread firmly, the mapper reads the angle for the black thread. The black thread is similarly stretched over that angle on the other protractor, and where the black and white threads cross the mapper makes first a little point, then a circle around it, numbering the point the same as that of the flag station. When all of the points have been located, they are connected with sketch lines. If the flag stations are close enough together, this will yield a highly satisfactory map. If the flag stations are not close enough together, then one will not know just how to sketch between these stations. Since that is often the case, it is necessary to take the map into the field and sketch between flag stations.

4. *The roving-point method: triangulation from a base line simultaneously from both ends onto a single stadia rod.* The setup for the roving-point method requires a definite base line measured out in the area. It is advantageous to locate the base line to one side of most of the area which is to be surveyed. Accurate location of points where angles are close to the base line is next to impossible. In operation a planetable with a sighter, a transit, or a compass is set up at each end of the base line with the recorder stationed midway between the two ends. In the field operation it is desirable to have two stadia rods in the hands of two stadia men but only one rod is in actual use at one time. Definite flag stations may be located, but this is not essential. However, it is desirable to have the students carrying the stadia rods study the area to be mapped with the director of the party so as to have a good idea of which points to select. The data sheet contains four columns: the first, the number of the point; second, the angle of direction or compass reading from the No. 1 end of the base line or the north end if the base line is approximately north and south; the third column, the angle or compass reading from the other end of the base line, or the south

end if the base line is approximately north and south; a fourth column for any notes that may be relayed back to the recorder.

In this method if the stadia rodmen get any distance away it is very important that the number of the points be maintained with considerable care. This is particularly so if the two ends of the base line are out of shouting distance from each other. A satisfactory arrangement for a class mapping a pond or a hook point is to have the base line 100 feet in length and the recorder midway between. An order of procedure is set up and maintained. In taking the observations, the stadia rodman sets up the stadia rod strictly vertical at point 1, which if a lake is involved may be at the shore; if it is another situation, it might be the location of a certain plant or some other feature. In either case, what it is should be shouted or relayed back to the recorder to put in the fourth column. If this is not possible, the number of the point should be recorded by the stadia person together with any necessary remarks and transferred to the record book later. A check on the number of the point needs to be made frequently; otherwise unrectifiable errors are introduced. When the stadia rod is vertical at the point selected, both compass men sight their compasses or transits on the stadia rod, allow the needle to come to rest, and read the compass direction or angle clockwise. The No. 1 end reports first to the recorder, who acknowledges by repeating the number and setting the number down in the proper column. The No. 2 end then reports, followed by the same sort of acknowledgment. As soon as both compass readers have reported and the data are entered, either the recorder or one of the compass men who is in sight of the stadia rodman throws both his hands up over his head, indicating that that point has been taken. The only other movements the compass men should communicate to the stadia men are movements of one hand to indicate necessary straightening of the rod. While the first point is being taken, the second stadia man has gone to the second point and sets up his rod as soon as the first point is cleared. Simultaneous readings are taken of this point and recorded, stadia man cleared, and meanwhile the first stadia man has proceeded to and set up for station 3. This procedure is continued until data are obtained from each point desired. The actual mapping is done in the class-

room from these data by the same method that was employed previously, *viz.*, the setting up of the base line in accordance with the scale selected on a map and the use of black and white threads to form the intersections (Figs. 7*B* and *C*).

Disadvantages: A good compass is required on which angles, preferably to at least half degrees, can be read easily. If any of the points are located where they cannot be seen from both ends of the base line, the point cannot be taken. If the point is necessary, it requires setting up a subsidiary base line or a traverse method from one of the known points. Another disadvantage occurs where, as in some lake surveys, there is no communication between the two ends of the base line; here there is always the chance that the numbers and stations will not agree. Telephone connections set up in the field may obviate this, or the wigwag system of signal flags may be employed, or a signal lamp using the Morse code may be used.

Advantage: The special advantage of the roving-point method is that it is an easy method for a class to learn, that it gives points very quickly, and plenty of them, so that they may be close together—a distinct advantage in mapping—and that it offers the possibility of locating stations where no flags may be put or maintained. Where depth to bottom of ponds or lakes is measured, this is virtually the only method that can be employed.

A modification of having the compasses on the raft to shoot to some point on the land edge is sometimes employed, but only rarely is the raft sufficiently stationary to permit this being done. The usual method is to have compasses located at both ends of a base line on shore, while on the boat one person in the party has flags which are held in certain positions, *viz.*, a get ready position, a take position, and the clear position. The take is usually an upright flag and the clear is a down flag. In practice a sounding lead is thrown out ahead as the boat moves slowly. With the lead on the bottom, the rope is maintained just taut but at an angle. As the boat passes over the lead the angle at the level of the water becomes a right angle. The depth is noted and the two compass parties on the shore sight and read the direction or angle. The number of each point must be the same for both boat and land parties. Occasional checks, however, are necessary to see

that the point numbers agree. Several such lines may be run across bodies of water, taking depths at intervals. The mapping follows the same procedure as given above.

5. *Triangulation departing from a base line, with angles or directions.* This method of triangulation may be used to cover long distances. It differs from method 3 in that the base line is used directly only in obtaining points at the beginning of the survey. The base line itself may be quite long, even miles in length. A base line must be set and accurately measured. Then from one end to a prearranged point or flag station, which is quite likely to be a hill or some prominent point in the landscape, direction is accurately taken. Another landmark is also taken. Then one proceeds to one and then to the other of these points and takes the angle or direction on the others. Continuing this process, triangles are built up in whatever direction and over whatever area it is required to form the base map. It is only necessary that each of the points be visible from two previous points. The data sheet will read: number of the point, other point to point, such as *A–B*, *A–C*, *B–C*, *C–D*, *B–D*, etc. To start with, the first point has had the angle or direction taken from both ends of the base line and the second point at least from one end of the base line. After that the base line may not be used. In mapping, the base line is located and scaled at what is thought to be a convenient position on the map and the mapper will then lay out the angles for each point. The intersections of the angles from any two points will be the location of the third point. After the map has been constructed, distances that are desired may be measured directly in accordance with the scale. For covering a large territory such as counties or states, or work in mountains where ground measurements are impossible or difficult, this is a standard method to use. The disadvantage is that it requires a good transit and accurate observation. It may require some difficult trail cutting to get to the point selected and may take a good deal of time; for instance, in using such a survey in the Rocky Mountains there might be more than a week between the taking of one point and the next. The advantage of course is that it lays a foundation for mapping of large areas for other uses. It would ordinarily not be used by an ecology class.

6. *Traverse (follow around; direction, distance).* The method of traverse surveying requires a compass and tripod—the better the compass and the firmer the tripod the more accurate the results—and a measuring tape or chain. From an ecological standpoint simple traverse mapping involves starting from a point, taking a compass direction on another point, and measuring the distance from the compass to the next point. A stake should be put in the ground at least temporarily. The compass is then moved to the point taken and another point sighted for direction and distance measured. This procedure is continued as far as necessary for the work in hand. If a traverse goes around a body of water, the final point should coincide with the original point. The method of traverse is particularly adapted to going through woods where the length of the different points can always be adjusted to what can be seen, thus avoiding the difficulties of triangulation (Fig. 7*D*).

Data may best be expressed in the following form: column 1, the two points between which the information is obtained, such as 1–2, 2–3, 3–4, etc.; column 2, the distance; column 3, necessary notes. In taking the distance the tape or chain should be as nearly level as possible as changes of elevation will make a difference on a fine map. On ordinary ecological problem classwork this would be important only if hillsides were included. At the same time the traverse is taken, change of elevation may also be taken. If trails are to be mapped or the edges of associations, the traverse method is the simplest to use.

7. *Planetable and telescopic alidade.* Where available, this expensive apparatus is preeminently suited for making detail maps of many points within range of the instrument. A telescopic alidade is essentially a telescope mounted on a straight edge, but capable of being moved in a vertical plane. A system of cross hairs makes certain measurements possible. For the average class it is better not to use this method where distances exceed about 800 feet. The particular advantage of the method is that when the field work is done, you have the map before you. A large planetable set up on a strong tripod firmly anchored is leveled off, a pin inserted in the board at the base station. Locating the pin may require a little preliminary measurement to

keep the area to be mapped on the board. The edge of the alidade is then kept in contact with the pin. In taking the points a stadia rod graduated into feet and tenths is used. For class purposes those stadia rods in which the feet are marked in red and the tenths in black are objectionable as soon as you get about 400 feet away from the instrument. The stadia rod must be long enough so that readings of distance may be made. To read as much as 800 feet would require for the full measurement a rod at least 8 feet high (more if the bottom of the rod is not visible to the observer). The stadia rod is set up on the numbered point and sighted through the telescopic alidade whose edge is touching the pin. When the perpendicular hair in the instrument coincides with the stadia, the alidade is leveled, if levels are to be taken, and then read. Great care must be exercised not to touch the instrument or the legs of the tripod. In reading the instrument there are three cross hairs to be read quickly. The middle cross hair is the level and the distance between the upper and lower cross hairs gives the distance that the stadia rod is from the focal plane of the alidade. That distance is a little over a foot in front of the alidade. (A statement of focal length accompanies the instrument.) In class practice it is a good habit to read the upper, the middle, and the lower cross hairs to a recorder who immediately subtracts the two halves, *i.e.*, the middle reading from the upper and the lower reading from the middle. If the figures are the same or different by less than a tenth of a foot, the point may be considered accurately read. The distance from upper and lower hairs, as read on the stadia rod, is then laid off along the edge of the alidade which has not been moved from the sighting in accordance with the scale selected. That is the location of the point. Any notations that need to be made can be put right on the map. Likewise the value of the level should be entered near the point. As soon as this is done, the usual sign of clearance, waving both hands over the head, is given, and the same or an additional stadia rod is set up for another point. The procedure is continued until the map is made. One special advantage particularly in outlining clumps of vegetation or of fine indentations of shore line within range is that if there is any doubt as to where the line should go, another point may be taken immediately in

the field. Another advantage is that direction and distance are obtained in one operation.

Each person in the group should have a chance at each of the duties, *e.g.*, reading the instrument, calculating, holding the stadia rod, or holding intervening vegetation aside when necessary to make a reading possible. For a good map, it is much wiser to train the reader (sighter) with a few preliminary points and let him do all the reading until all the important part of the map is completed, then let other students have their turn at putting in points. Since the original setup is usually selected on the ground, it may be a wise thing to locate it, if possible, from certain landmarks, but this is not absolutely essential for mapping bogs or ponds as far as the map is concerned.

The main disadvantage of alidade planetable mapping is that it utilizes an expensive instrument that requires great care in reading. It cannot be used in rain unless a shelter can be built over the planetable. When finished in the field, the map is done. There are therefore no data to give to a class in the laboratory from which to construct a map.

8. *Contouring.* In making contours two types of surveying may be employed. The location of definite points may be gotten by any one of the above methods and levels run between the points. A very common method is to use a combination of the traverse and contouring methods. For this purpose a line is set up at right angles to a section line or other line agreed upon and traverse run at intervals. Along with the traverse at either regular or irregular but measured distances, the elevation is taken. Where sections are surveyed in the field, traverses a quarter of a mile apart are often used, or they may be closer or farther apart, depending on the situation. When the field data are assembled in the laboratory it is necessary to lay out the base map and put in the figures of elevation. Smoothed out contours may then be drawn. While laboratory work in some types of topography may yield a satisfactory map, it is wiser to check the map on the ground. This is particularly necessary in case of streams entering the picture where the contours should be run upstream in crossing. If there are hills or other points of vantage, artificial or natural, the job of contouring is simpler. A well-made con-

tour map is extremely useful in illustrating data of various sorts, such as distribution of certain types of plants or plant associations, or laying out experiments, etc.

9. *Photography.* Wherever a point of vantage obtains, photographs may be taken of the landscape. From such photographs a skilled person may construct a usable map. The points to remember are that in each photograph there is perspective, and allowance must be made for this in laying out the map. If it is possible to take a photograph from more than one point, it is advantageous to do so. The amateur may try his hand, but if there is an accurate map available he will usually find that, although photography may be advantageous in arranging details, his basic outline map will not be nearly as good as he expected. When one has no other choice in the matter, photography may certainly be used. In mountain work suitable filters are of great advantage in penetrating the haze often present around mountain peaks.

10. *Aerial photography.* The taking of pictures from airplanes makes it possible to map a considerable area of ground in a very short time, but if there is no control on the ground, *i.e.*, accurate surveys made on the ground, with landmarks that can be recognized in the aerial photographs, the maps that result will not be so useful as may be desired. In taking a series of maps it is important that there be a reasonable overlap and that the same angle be employed, which theoretically should be a right angle, although a slant will make certain features more discernible. From the negatives prints are made on gelatin which can be stretched. Primary traverses and triangulations in the area locate landmarks. The gelatin is stretched or skewed to make these landmarks on the gelatin fit the landmarks on the ground. This matching when completed is then photographed and this photograph is the airplane map that will be used. Difference in density of the original negative or of the prints makes it appear as an overlapping patchwork which can hardly be avoided, but from this map a black-and-white or blue-and-white tracing may be made which will serve as a map to use. Without control on the ground the results are distinctly unsatisfactory.

In mapping vegetation by air different plants have a different appearance, so that an airplane map shows lines of transition.

If, however, one does not have ground control, he may later discover that some of the lines were not different types of vegetation but merely different ages, or he may have failed to get the edges of the vegetation in case the appearance was similar. In general a line between conifers and hardwood vegetation shows very well. For resurveys aerial photography is particularly advantageous as a great deal of information is obtained instantaneously and many comparisons may be made. In rough country, likewise, by aerial photography one may be able to get data for a whole district in a few minutes whereas a whole summer or more might be necessary to map it by the ordinary surveying methods. Again, let it be repeated, without ground control the aerial map may be considerably off.

NOTE: The average class will not be able to make aerial maps by themselves, but it is often possible to obtain prints of pieces that can be organized into a map. New techniques and instruments for viewing aerial photographs have been developed and used to good advantage in the Second World War. If available, use by advanced students in special problems is advantageous.

Exercise 26. Mapping or Map Making

Using one or another of the methods dealt with above make a base map of an area selected.

Repeat using another method and another area.

After making a base map, put on it (possibly with color) suitable items of interest, such as particular trees or other plants, types of vegetation, transition lines. Indicate location of soil sampling, temperature reading, or other items desired.

CHARTING

Much ecological data can be expressed through various forms of charting. Where this is possible, a good deal of data can be gotten on a small space. While there are many forms of charting, only a few will be mentioned here. The teacher or student is expected to develop others for particular purposes.

Charting for various climatic functions such as temperatures, pressure, and rainfall is universally used. Lines are used in charting temperature and pressure, while precipitation is repre-

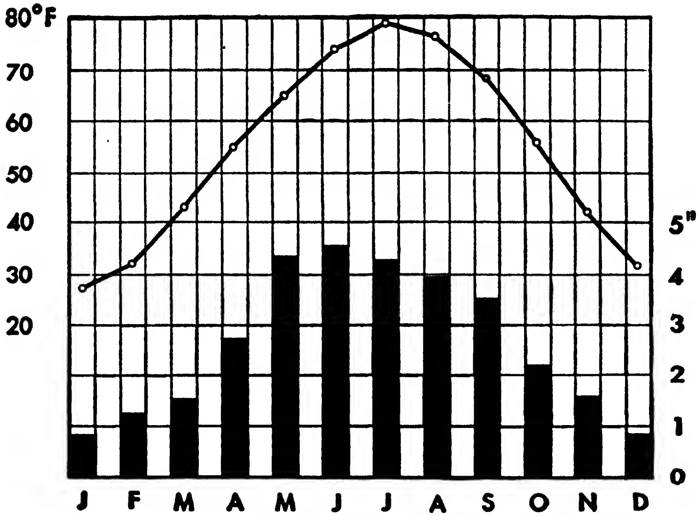


FIG. 8. Average temperature by months in degrees Fahrenheit and average rainfall by months in inches for Manhattan, Kansas.

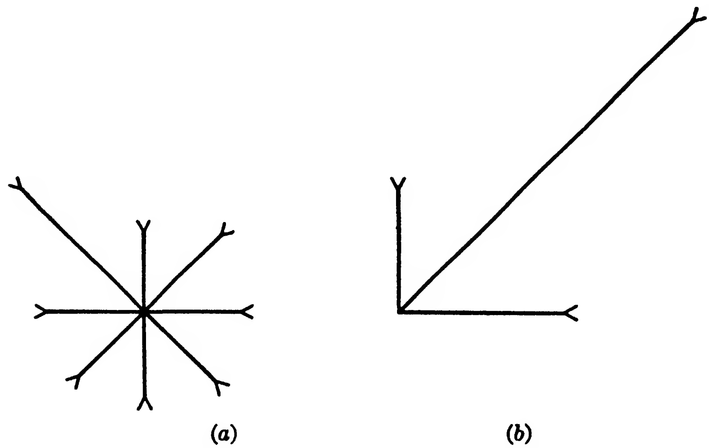


FIG. 9. Wind roses for the month of January: (*a*) North Pacific Ocean in latitude 37°N, longitude 137°W. (*b*) Just off the coast of Leyte, Philippines, in the northeast trade-wind belt. The length of the lines indicates the proportion of time in which the wind blows from the direction indicated.

sented by columns (Fig. 8) and the proportion of the time the wind comes from the various directions by wind roses (Fig. 9).

Flower Charts. On a chart expressing the months, the time of flowering may be indicated by a heavy line for each of as many different plants as desired. If the plant has a long initial period before a peak blossoming, the heavy line may gradually widen

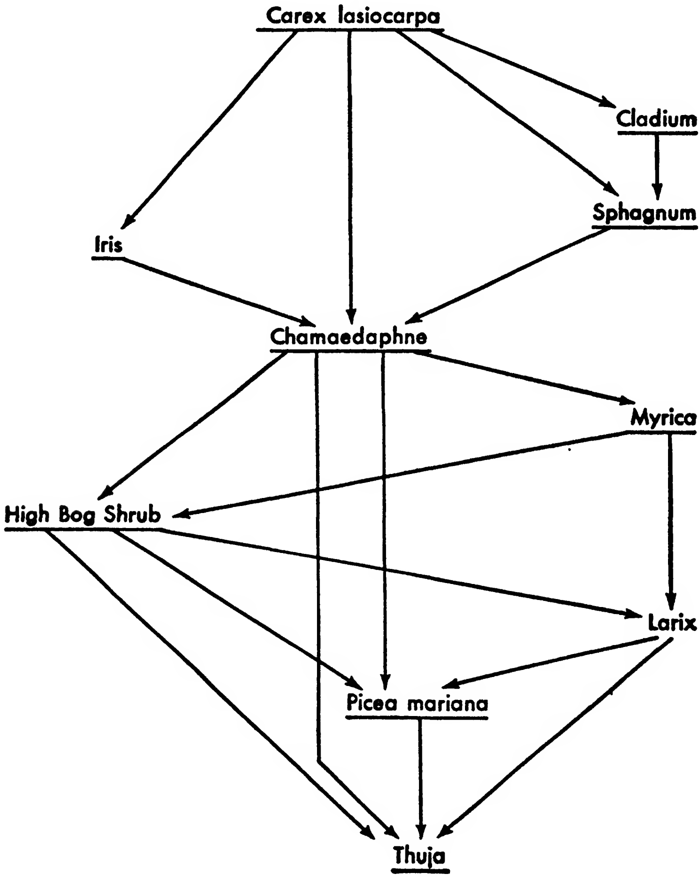


Fig. 10. A succession diagram of a northern Michigan bog. Arrows show direction of succession from one association to another.

to a maximum and then break away gradually or suddenly as the facts indicate.

Succession Charts. This is one of the best ways of showing them. It may be done in different ways. In setting up a suc-

cession chart, one may take all of the associations involved or pick out the important ones. In either case the names of the associations may be typed on a thin piece of cardboard which can then be cut out. The names may then be arranged on a sheet, the size determined by the exigencies of the situation, so that the connecting lines will be as free from crossing one another as is possible. If associations of different importance are used, the more important may be in capital letters or in larger type if printing is employed. Arrows connecting observed succession will build up the chart. Whether the climax association

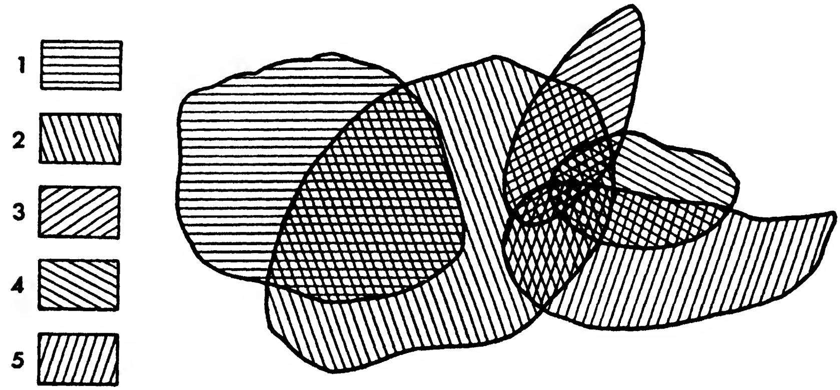


FIG. 11. Diagram showing overlapping ranges for five species. The angles of the lines differ from each other by 72 degrees.

should be at the top of the page, the center, or the bottom are points of individual preference, as a rule. Since we usually read down, many succession charts have the initial conditions at the top. The width of the stems of the arrows connecting the names of the associations gives an indication of the frequency of that succession (Fig. 10).

As a method of taking notes, the charting of observed successions is very handy and a good deal of information can be expressed in a very short time.

TO SHOW OVERLAPPING RANGES

It is often desirable to show ranges of plants which overlap and consequently make the use of colors or shades too confusing. A simple method of getting around this is to outline in turn the ranges of the plants considered, then to put in parallel lines in

accordance with radiation diagrams previously set up. The number of ranges that may be shown is considerable, if mathematical accuracy in drawing is maintained. If, as in Fig. 11, five plants are shown, the lines will be 72 degrees apart from each other.

Additional examples of this method are illustrated by figures on pages 378 and 379 of the ninth volume of the *Botanical Review*, 1943.

POLYGONAL EXPRESSION OF DATA: POLYGRAPH[1]

While data may be expressed in the form of graphs for each item, often it is distinctly advantageous to concentrate some of the data in a more concise kind of expression, of which polygonal expression is one useful type. As many radii equidistant from each other as are needed are drawn from a point. Scales or parts of scales, each suitable to the material for a given radius, are then arbitrarily chosen and the values in question are then marked on the proper radius. A line connecting these points constitutes the polygon. If a series of diagrams is used, the same scale in the same position must be used to permit comparison (Fig. 12).

Each radius may be used for some function of ecological work. If climatological data are to be expressed, one radius may give the average temperature for whatever period is selected, a second radius may give the maximum in the period, a third the minimum, a fourth may give the variability, a fifth may give the rainfall, a sixth the maximum rainfall in one day, and so on. Such polygonal graphs may be set up for each month, year, or whatever period is desired. They may be interpreted by inspection and will be very satisfactory where more than three items are to be expressed at one time. In the *Bulletin of the Torrey Botanical Club* (**69**:647–660. 1942) Oosting and Reed show by such graphs the establishment of a white-birch community on cutover pulpwood land in northwest Maine. They have used four radii to indicate percentage of dominant abundance, percentage of frequency, percentage of total size of the classes represented, and percentage of total dominant basal area, with the center zero of each characteristic. With this method of expression, very neat figures may be set up. The disadvantage sometimes is that size

[1] Cf. Weaver and Clements, *op. cit.*, pp. 35–36, after Lutz.

may require too small a scale for fine distinctions, but the advantage of correlating different things in one small diagram may outweigh this. Another disadvantage may be the inclination to put too many data into one figure. This makes the printing too fine unless it is done on quite a large scale.

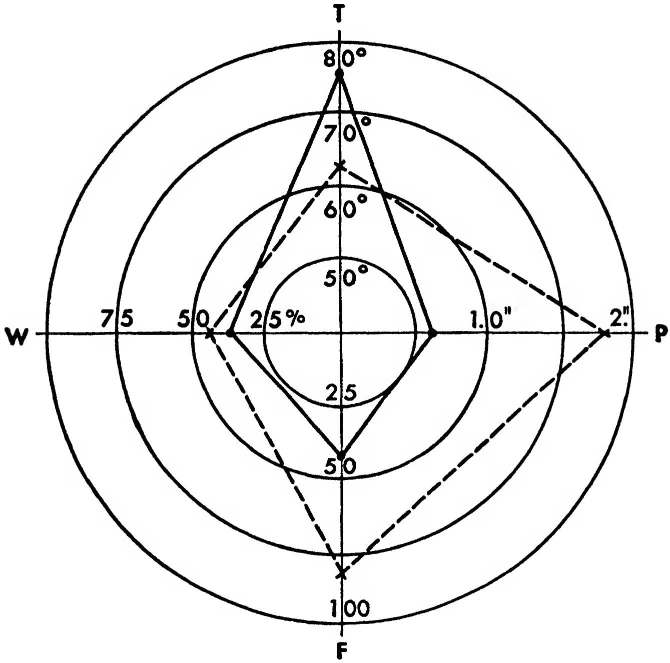


FIG. 12. Polygraphs. Two locations, one expressed by continuous line, the other by dashes, showing differences in each of four characteristics on four different radii: *T*, temperature in degrees Fahrenheit; *P*, precipitation in inches; *F*, percentage of plants in flower; and *W*, percentage of the time that the wind is in the northwest.

Exercise 27. Charting

Chart data obtained in classwork or suggested by the instructor in one or another of the forms indicated above.

Repeat in connection with other exercises or as an exercise in itself.

COMPARISON OF EVALUATION SCALES

It is frequently necessary to choose between expressing certain data numerically or by common descriptive terms and to

change from one to the other. Where possible it is desirable to set up a scale of units and express the points directly. This is particularly so in evaluating frequency. One plant that is reckoned abundant will have a frequency of 95, another 80, etc., differences which the term "abundant" fails to bring out.

In view of the fact that terms are used more commonly, efforts to evaluate them are worthy of consideration. Whether a scale of 1 to 5 is better than 1 to 10 is a question depending on the data in which one is interested. On a 1 to 5 scale, one can use a series of terms which are rather well understood as follows:

0—absent
1—rare
2—scarce
3—common
4—abundant
5—very abundant

If finer divisions or categories are desired, it is better to express them numerically.

UNEQUAL SCALES FOR RATING SPECIES IN COMMUNITIES

While most people are content to use such terms as rare, scarce, common, abundant, etc., it is often desirable to be able to express such ideas in figures. To this problem A. G. Vestal has given considerable attention.[1] Since we employ the decimal scale for many purposes, that scale would seem to give satisfactory results; however, decimal scales may be set up on different bases. The units between may be the same throughout or they may themselves follow a pattern. A class exercise might be set up which would enable the students to figure out a suitable pattern for themselves. Where unequal scales are used, the first principle is that the greatest inequality should be toward the lower end of the scale and diminish to the upper end of the scale. One such scale is as follows:

[1] Vestal, A. G., "Unequal scales for rating species in communities," *Amer. Jour. Bot.*, **30**:305–310. 1943.

Scale	Difference	Percentages	Scale	Difference	Percentages
1	2.5	97.5–100	6	9.9	64.5–74.3
2	3.7	93.8–97.4	7	11.9	52.6–64.4
3	5	88.8–93.7	8	14.4	38.2–52.5
4	6.4	82.4–88.7	9	17.3	20.9–38.1
5	8	74.4–82.3	10	20.9	0–20.8

If this scale gives too fine a difference, scales of five units are often advantageous. One which has been satisfactory from this standpoint is given below.

Scale	Difference	Percentages
1	6	94–100
2	11	83–93
3	18	65–82
4	26	39–64
5	38	0–38

For other purposes other rates of inequality may be set up. Similar results may be obtained by the use of semilogarithm paper.

AQUATIC SITUATION

The following is a brief outline of the field, an important part of field ecology.

I. Type of Body of Water.
   - *A*. Oceanography—oceans and seas (beyond the scope of beginning classwork, as a rule).
   - *B*. Limnology [that part of ecology which deals with inland waters—see "Limnology" by Paul S. Welch (McGraw-Hill Book Company. 1935) and "Limnological Methods" by the same author (The Blakiston Company. 1948)].
     - *a*. Lentic (standing-water series).
       - (1) Lakes (fresh or salt).
       - (2) Small lakes, ponds, boglakes.
       - (3) Artificial lakes.
     - *b*. Lotic (running-water series).

(1) Streams, rivers, creeks; permanent, temporary, and artificial.
(2) Springs.
(3) Hot springs.

II. Study.
- *A*. Factors.
  - *a*. Physical.
    - (1) Depths.
    - (2) Temperature.
    - (3) Waves and wind.
    - (4) Turbidity and inherent color.
    - (5) Flow curves.
    - (6) Icework.
  - *b*. Chemical.
    - (1) Dissolved oxygen.
    - (2) Free CO_2.
    - (3) Hydrogen-ion concentration, pH.
    - (4) Monocarbonates.
    - (5) Dicarbonates.
  - *c*. Biotic.
    - (1) Plants.
    - (2) Animals.

III. Vegetation.
- *A*. Recognition of communities.
- *B*. Individual study of communities.
  - *a*. Quadrat studies.
  - *b*. Transect studies and profiles.
  - *c*. Individual plants—root systems, depth of water, etc.
- *C*. Swamp, marsh, and bog.
- *D*. Change to land.
  - *a*. Abrupt.
  - *b*. Succession.
- *E*. Alternation.
- *F*. Zonation.

IV. Experimentation: Artificial Vegetation, Etc.

Where aquatic areas are studied ecologically one may employ the same general procedures as are utilized on land areas, with suitable modification when necessary.

ROOT SYSTEMS OF AQUATIC PLANTS

An outstanding feature of aquatic plants is the development of the root system. This fact, combined with the relative ease of excavating the major part of the root system, in case the water is not too deep, makes the study of root systems an important feature of aquatics. Under aquatic conditions one is likely to find two types of roots. These are known as the feeding roots and the anchoring roots. While all of the roots can absorb water and minerals and serve in some degree for anchorage, it is quite common to find early roots growing directly down and being rather spongy in texture for a while. At some stage in their downward development they contract, which has the effect of pulling the rhizome down into the mud and thus firmly anchoring it. Some feeding roots may branch from contractile roots, but in general feeding roots arise from the rhizome and branch not far from it, making a dense growth in the upper layers of the mud or sand under the water.

Different plants may be dug up by members of the class. The roots should be kept wet until the study is completed. Drawings or photographs may be made on which later comparisons may be based. (Cf. Sherff, Earl E., "The vegetation of Skokie Marsh, with special reference to subterranean organs and their interrelations," *Bot. Gaz.*, **53**:415–435. 1912.) A knowledge of the root system explains the resistance of certain aquatic plants to disruptive features of the environment. If the same species of plants grows in different types of bottom, such as sand and clay, a contrast between the root systems may be brought out.

Exercise 28. Root Systems of Aquatic Plants

Dig up half a dozen or more important aquatic species. Study. Sketch or photograph. Correlate with position in environment by making a trench through the area of aquatic plants. Carefully tease out the roots of the plants and sketch at the proper level on cross-ruled paper. In case of muddy water in the trench a sufficient vertical section of the soil and root mass should be laid out on dry ground and studied.

DEPTH OF WATER IN WHICH AQUATIC PLANTS ARE GROWING

Particularly in working with aquatic situations it is often desirable to know the depth of water through which the aquatic plants will grow. Efforts to ascertain the greatest, least and average depth at which such plants may grow involves many measurements. If the water is not too deep, measurement may be made with measuring sticks graduated to meters and tenths. As many measurements as possible should be made within the time allowed. Sticks more than 3 meters long are too unwieldy for convenient use. Waxed rope in which threads have been inserted or on which markers have been painted may be used to suspend a weight. Consideration of the type of bottom under the water needs to be made, especially where there is fine muck or a false bottom. Depth in bogs filled with peat is best determined with steel rods such as are used with the Davis type of peat borer. More special cases require more formidable gear such as that developed by Ira Wilson[1] or by well diggers.

A complete study may be made for the different kinds of plants, both to determine the maximum depth in which they grow and, if a species continues up on shore, how far above the water table the plants will grow.

Exercise 29. Depth of Water

By measuring down from the surface of the water, determine the greatest and least depth at which certain plants are growing in the lake or river under consideration. Organize a diagram to show the greatest and the least depths at which the various species will grow.

Repeat in other water areas and compare.

PHYSICAL FEATURES OF THE WATER

The temperatures at various depths may be determined with special thermometers made so that the reading is held until a new set is made after being brought to the surface (Nagretti and Zambra thermometer) or by an electric setup.

[1] WILSON, IRA T., "A new device for sampling lake sediments," *Sedimentary Petrology*, 11:73–79. 1941.

The turbidity or light penetration is taken by the use of a Secchi disk.

The mechanics of stream flow, wind and wave work, erosion, and icework offer many problems in physics. Their effects on both plants as individuals and on vegetation are often quite conspicuous.

If good examples are available such exercises as follow may be set up.

Exercise 30. Lake Study

Contrast the various shores of a lake with respect to the following:

Amount of wave and icework.

Position with respect to prevailing wind.

Width of strand.

Character of the shore: rocky, sandy, marly, etc.

Erosion.

Kind and amount of vegetation in the water-land ecotone, shown by transects taken from water to land (Exercises 23 to 25).

Associations, alternations, successional relationships. Compare with those found in streams (Exercise 31) and boglakes (Exercise 32).

Exercise 31. Stream Study

Contrast various parts of streams: shore, bottom, outer and inner parts of curves, pools, rapids, and waterfalls with respect to the following:

Wave action.

Flow effects—in other words, water erosion.

Kind and amount of vegetation in the water and along the shore under these various conditions. Take transects. Note associations, alternations, successional relationships, and compare with those of lakes.

Exercise 32. Boglake Study

Contrast boglakes, with and without wave action, with ordinary lakes and with streams, in regard to the following:

Physical, biotic, and chemical factors.
Development of a floating mat.
Amount of organic accumulation.
Associations, successional relationships.

WATER CONSTITUENTS

Various substances are dissolved in the waters of streams and lakes. Through chemical analysis in the laboratory of samples taken in the field, the kinds and quantities of such solutes may be established. The more commonly determined include dissolved oxygen, free carbon dioxide, hydrogen-ion concentration (pH), monocarbonates, and dicarbonates. (For pH see also Exercise 45.)

Exercise 33. Water Constituents

As opportunity offers and material is available, determine some of the constituents of water as noted above.

It may be feasible to determine water constituents above and below sewage outlets or above and below outlets of industrial plants. Study the effects on plants, if present in the water and along the shore.

CHARACTER OF THE BOTTOM

Specialized dredges are used to bring up known quantities of bottom. The samples are then studied in the laboratory from various standpoints. (See Welch, "Limnology," pp. 25–28.)

Exercise 34. Bottom Samples

As opportunity offers and material is available study the physical, chemical, and biotic constitution of samples of the bottom of lakes, streams, and boglakes.

ZONATION[1]

The study of zonation or the development of belts of vegetation along a river or around lakes or ponds is always instructive. In such a study one or another of the transect methods is

[1] Cf. Weaver and Clements, *op. cit.*, pp. 6–7.

most satisfactory. A map showing the various zones in the area is a good way of expressing the results. This should be supplemented by a study of the physical factors using the proper methods for each.

If a long time is available, mass operations such as moving blocks of sod containing land plants into various depths of water may be carried on and studies made of the dying out or possible rooting and development of any plants in the original block.

A study of variations from week to week, month to month, or year to year in the water level, particularly of lakes, is always an interesting one where it can be carried on. The reactions that take place in the vegetation along the shore are sometimes conspicuous.[1]

Exercise 35. Zonation

Along a stream or around a lake or pond identify the zones of vegetation. If a base map of the area is available, sketch in the different zones. In the absence of a base map, first make a map, then locate the different zones on it. Take transects, both line and associational, in a suitable number of places from the water up into the upland vegetation. Locate these on the map and let them help determine the proper location of the different types of vegetation.

ALTERNATION[2]

In the course of studying zonation, different plant groupings may be found in the same relative position in the sere from water to land. This phenomenon is known as alternation. It is more frequent along rivers than around lakes. To ascertain whether it is purely alternation or whether there is a successional relationship between the groupings requires the study of several occurrences of both in the same area.

[1] In one case investigated at the University of Michigan Biological Station the relationship between the level of the water and the average temperature for July was established for the blossoming of *Utricularia resupinata* in the Douglas Lake region. It required both low water and a July temperature distinctly above the normal average for this Utricularia to flower. GATES, F. C., "Conditions for the flowering of *Utricularia resupinata*," *Lilloa*, **5**:159–162. 1939.

[2] Cf. Weaver and Clements, *op. cit.*, pp. 7–9.

Exercise 36. Alternation

Include, if possible, examples of alternation on your map of zonation, using different shading, or different markings of the same color.

FACTORS OF HABITAT

INTRODUCTORY TO FACTORS

Various factors of the environment affect the plants in vegetation. The single or occasional determination that a class may make of the factors of the environment will illustrate the method but cannot furnish sufficient data for a complete study.

One should guard against too much study with instruments at the expense of studying the plants themselves. For many factors a single determination has but little value and yet that single determination is all that the class may be able to make. Averages of factors as measured by weather-bureau stations may be obtained from weather-bureau figures, but it is wise to remember that the actual weather-bureau figures are not obtained in the exact field which the class has under consideration. In addition one should remember that plants undergo the extremes as well as the means and the former are more likely to be disastrous. Measurement of the following factors is usually most valuable: heat (temperature), precipitation, humidity, light, wind, evaporation, soil composition, and soil water content, each of which will be considered in an exercise following.

TEMPERATURE[1]

The measurement of heat is important in ecology, not only to express present temperature, but also to express climate. The temperature of many things may be determined, but that of the air and of the soil are those most frequently sought. For most of these measurements ordinary thermometers are used. The reading is made while the thermometer is immersed in the place or medium whose temperature is required. To obtain climatic data recording thermometers of various types may be employed.

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 356–379; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 83–97.

The simplest are those in which two metals are welded together, the unequal expansion and contraction of which operate levers which move a marker in contact with a revolving drum carrying specially ruled paper. Electrical instruments may also be used for ecological work in the field. The commonest figures sought are the temperature of the air, the temperature of the wet bulb, and the temperature of the soil at different depths. Ex-

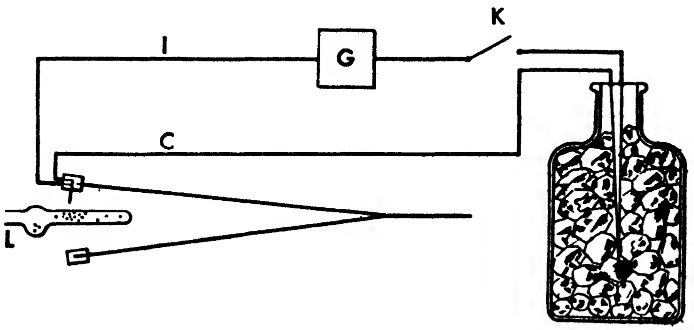


FIG. 13. Thermocouple setup (not according to scale). Two kinds of wire, iron, *I*, and constantan, *C*, are fused together at the ends. One fused end is maintained in cracked ice in a thermos bottle, the other is set in a cork at the end of one tine of a pair of pincers. The other tine is capped with a similar piece of cork. A galvanometer, *G*, and a key, *K*, are included in the circuit. Shown also is a portion of a leaf, *L*, whose temperature is to be taken when the other end of the fused wires is imbedded in the mesophyll.

pression of climatological data involves a daily record so that averages may be obtained. In such cases, the average maximum and the average minimum, from which the mean is calculated, are the usual figures recorded, although they are not always the most valuable from the standpoint of plants.

To obtain temperatures inside a plant, if the plant is sufficiently large, a hole may be bored or an opening made and a thermometer inserted into the tissue. Leaves may be rolled around the bulb of a thermometer to obtain their temperature, being careful not to allow the hand to influence the reading. To obtain temperatures inside leaves and other parts of plants, the use of a thermocouple is the most desirable method. The thermocouple action results from the fact that when two different metals are fused together at the ends and the ends are at different tem-

peratures, an electromotive force exists between the two metals. By placing one set of fused ends in cracked ice in a Dewar bulb or in a thermos flask, for constant temperature, and the other fused end inside a leaf, a difference of potential is set up, which may be evaluated on a sensitive galvanometer or potentiometer placed in the circuit as shown in Fig. 13. Calibration of the system by finding out the amount of deflection of the galvanometer needle when known temperature differences are used makes it possible to read leaf temperatures directly. Wires of iron and constantan (60 per cent copper and 40 per cent nickel) make an excellent pair to use for this purpose. For work with plants the exploring end may be nearly as fine as a needle and be mounted in cork at the end of one tine of a pair of forceps or pair of scissors, permitting easy and rapid manipulation.

The temperature of the soil may be taken by digging a small well to any desired depth and plunging a thermometer laterally into the wall, or thermometers with different lengths of stem may be employed. Regular soil thermometers are contained in a case whose steel-pointed end facilitates pushing them into the ground to the proper depth. The reading is taken as soon as the mercury becomes stationary.

In water various thermometers are used, one of which is the Nagretti-Zambra thermometer, which is so made that it can be put down to the desired depth, the reading established, and the mercury column broken by inversion, then the thermometer brought to the surface and read. Pulling an ordinary thermometer up through water would change the reading unless the water was of uniform temperature throughout.

Standard weather-bureau instruments exposed in standard shelters include at least maximum and minimum thermometers. Sun temperatures may be obtained from a black bulb *in vacuo* which may be set up pointing to the North Pole (in the Northern Hemisphere) in an area to which the sun has access throughout the day.

Exercise 37. Heat Measurements

With the thermometers furnished, take temperatures as directed of such things as the following:

The air in the open and in shade, in crowns of plants.

The soil on the surface and at various depths.

Water of lakes, springs, streams; surface and at regular depths to the bottom.

Soil of various colors in full sun and in shade.

Leaves under various conditions, by rolling them around the bulb of the thermometer, taking care not to let the warmth of the hand interfere.

If time permits, sufficient readings may be taken to permit at least some evaluation of the micrometeorology as distinct from the standard Weather Bureau records of the nearest station.

PRECIPITATION[1]

The amount of precipitation, whether in the form of rain or snow, is of great importance to plants. For ordinary ecological field work it is not usually feasible to obtain the records from given spots in the field for a long time. It has been customary, therefore, to take weather-bureau figures from an adjacent town if that is possible, or to maintain weather-bureau instruments at a base station, using those records for the general averages of the region. Admittedly, these are not the actual readings for the spot worked. How far they depart is seldom known. It may be considerable in instances.

The Weather Bureau uses an 8-inch metal gage in which to collect rain; however, any sort of sharp-lipped container may be used in the field. A funnel leading into a bottle is a simple arrangement. The neck of the bottle must be protected from receiving rain except through the funnel. To calibrate one must know how much water in the bottle equals 1 inch of precipitation. A graduated cylinder may then be used to make the measurements, in hundredths of an inch or fractions of a millimeter.

Interesting experiments may involve the setting up of several rain gages, some in the open and some under different types of trees or other plants. In one such series Homer Jack (*Ecology*, **16**:120–121. 1935) discovered that 0.12 of an inch of rain must

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 210–214; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 111–125.

fall before any moisture gets to the ground through a mat of the lichen, Cladonia.

Exercise 38. Precipitation

With the use of figures obtained by the class or data from a regular or voluntary weather-bureau station, plot out the rainfall of the area in which the work is done.

RELATIVE HUMIDITY AND VAPOR-PRESSURE DEFICIT[1]

The relative humidity is the percentage of moisture actually in the air at any given time compared to the total amount of moisture that the air at that temperature is capable of holding. The actual amount in the air is known as the absolute humidity and may be determined by drawing air through gas chambers containing chemicals to remove the moisture from the air. This is seldom feasible in field work; however, the absolute humidity may be calculated along with the relative humidity if the temperature of the air and of a wet bulb be taken simultaneously. To do this an instrument known as a psychrometer may be made by fixing two matched thermometers on a rack which may be swung around in the air or set up on an egg-beater-like arrangement and rotated in a small compass. If wind is present the thermometers may remain stationary. The thermometers are placed so that the bulb of one projects an inch or more below that of the other. The lower one is covered with a jacket of linen tied close to the bulb. Before using, this should be wet with distilled water and the whirling or twisting completed before the linen dries out. In reading, one reads both thermometers at short intervals while the cloth is still wet, until neither thermometer changes in a period of 5 seconds. Reference to U.S. Weather Bureau psychrometric tables then gives the relative humidity, absolute humidity, dewpoints, etc. The greater the lowering of the temperature of the wet bulb, the lower is the relative humidity. The same number of degrees of lowering at high temperatures, however, indicate a higher relative humidity than

[1] Cf. Weaver and Clements, *op. cit.*, pp. 333–346; Braun-Blanquet, *op. cit.*, (tr. and rev. by Fuller and Conard), pp. 125–137.

the same difference at lower temperatures, since the ability of the air to hold moisture accelerates with increase in temperature.

Vapor-pressure Deficit. The vapor-pressure deficit is expressed in millimeters or in inches of mercury. It is the difference between the pressure exerted by the water vapor actually present in the atmosphere at a given temperature and the pressure exerted by the water vapor in a completely saturated atmosphere at that temperature.

The vapor-pressure deficit can also be calculated from the saturation vapor pressure for the current dry-bulb temperature and the saturation vapor pressure for the current dewpoint temperature. The current dewpoint may be found in the U.S. Weather Bureau psychrometric tables, if one knows the current wet- and dry-bulb temperatures. Only if the temperature is the same do equal values of relative humidity indicate equal vapor-pressure deficits.

Copyrighted nomograms (see page 117) permitting rapid determinations of these values, once the wet- and dry-bulb temperatures are known, are to be found in *Ecology*, **21**:505–508, 1940.

If a series of relative humidity determinations are made, one will generally find that there is a close relationship between the temperature and the relative humidity, the latter sinking during the day as the temperature rises. This is primarily because the actual amount of water vapor in the air may remain essentially the same irrespective of the temperature.

Exercise 39. Relative Humidity and Vapor-pressure Deficit

With a psychrometer obtain dry-bulb and wet-bulb temperatures in different places and at different times of the day, as directed. By reference to tables furnished give the relative humidity, the absolute humidity, and the dewpoint temperature. Calculate the vapor-pressure deficit.

LIGHT[1]

There is no perfect instrument to determine the exact amount of light that plants actually use; consequently all light meters, or photometers, that are used simply give relative values which

[1] Weaver and Clements, *op. cit.*, Chap. XIV; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 97–110.

may be useful in so far as those figures are of value. Clements used photographic paper which darkens to a given color in so many seconds. The reading consists of counting the seconds from the instant of exposure until the paper matches the color of the standard alongside of it.

Such photometers as the McBeth Illuminator give the value in foot-candles of the light from the standpoint of the instrument. Readings may be made one after the other in different habitats and the results recorded.

The photometers used by photographers may also be used to make comparisons in light values.

Exercise 40. Light

With whatever instruments are available, determine the light value by comparison with daylight in various situations.

WIND[1]

Generally speaking, the determination of wind is of but minor importance in ordinary ecological studies; however, maximum values do affect plants and are important in seed distribution. Wind direction is determined by a wind vane and the velocity by an anemometer. Small hand types of wind meters may be used. Record is made of the number of feet or meters rotated by the device in a given time and expressed as feet per minute, feet per second, meters per second, or miles per hour, etc. The weather-bureau type is a three-cup anemometer set as high as reasonable in the air. It records the total number of miles the cups have turned. The rate per hour is obtained by dividing the miles by the elapsed time. Weather-bureau stations record the direction of the wind every 5 minutes, from which may be obtained the percentage of wind from each of the octants. With these figures at hand a wind rose may be set up (Fig. 9).

Exercise 41. Wind

If desirable for the work in question, with wind meters or anemometer determine the velocity of the wind. If figures for

[1] Cf. Weaver and Clements, *op. cit.*, pp. 346–350; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 145–158.

the number of hours the wind blew in any direction are available, construct a wind rose by making eight arms or radii project from a point. The length of each arm represents the number of hours the wind blew from that direction in accordance with the scale used.

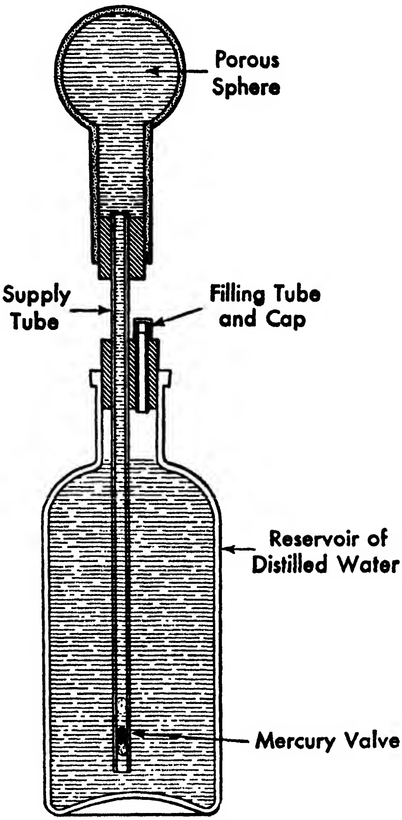


FIG. 14. The Livingston spherical atmometer setup. (For explanation, see text.)

EVAPORATION[1]

The amount of water evaporated into the air affects plants in two principal ways. It removes water that might otherwise get into plants through the roots and it makes the air moister, so that the amount of water lost by transpiration becomes less than it otherwise would be. Evaporation may be measured directly from pans of water freely exposed (but protected from birds and other animals) either by restoring the quantity necessary to fill to a mark or by weighing the dish. Various instruments known as evaporimeters or atmometers may also be used. Perhaps the commonest in evaporation work has been the Livingston atmometer, a porous clay sphere which is set up above a water supply maintained by hydrostatic pressure. Reading consists in adding known amounts of water to fill to a mark on the neck of the bottle or tube. Mercury valves in the supply line prevent the entrance of rain. The simplest mercury valve, as illustrated in Fig. 14, is made by imprisoning a globule of mercury between two plugs of glass wool in the lower part of the supply tube. Other substances may be used to form the plug as long as water may be

[1] Cf. Weaver and Clements, *op. cit.*, pp. 350–355; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 137–145.

pulled up through them as evaporation takes place from the porous sphere. Other types of rainproofing valves have been developed. Some are illustrated in an article by Frank Thone in *Ecology*, **5**:408–414, 1924.

Such atmometers are set in position in the vegetation at the ground or at various levels above and read at intervals. Comparisons show the effects of different types of vegetation in accelerating or retarding evaporation. Such instruments can be used only in the frost-free season. If a blackened sphere is used along with a white one, the value of insolation or solar exposure and evaporation may be obtained, since the two evaporate at the same rate in darkness but the black evaporates faster in sunshine.

Exercise 42. Evaporation

With Livingston atmometers or other instruments set up in the vegetation, ascertain the amount and rate of evaporation for comparisons.

In setting up an atmometer, soak the porous cup in distilled water overnight. Insert the supply tube with the mercury valve through both rubber stoppers, as shown in Fig. 14, and the filling tube through the reservoir stopper so that the mark etched on the tube is above the level of the stopper. Fill the supply tube completely with water by suction and immerse in water in a sufficiently tall battery jar. Twist the rubber stopper into the neck of the porous sphere while both are under water. Invert into the reservoir bottle of distilled water, stopper tightly, and fill to the mark on the filling tube. Put a loose cap over this tube to keep out dust but still allow air to enter freely. The atmometer is then ready for use. As water is lost from the porous surface the water level in the reservoir goes down. Reading consists of replenishing this water from a pipette or graduated cylinder and recording the amount of water needed and the time elapsed since the earlier filling. In the field, atmometers should be firmly attached to stakes driven into the ground or by some arrangement to maintain them in the position desired.

A season's results should be plotted on cross-ruled paper and compared with data from other atmometers maintained in different habitats.

The transpiration of plants, i.e., the evaporation from living surfaces, may be determined by the loss in weight during a known lapse of time, when the loss of water is limited to a known surface of a living plant (see Exercise 59*f*.)

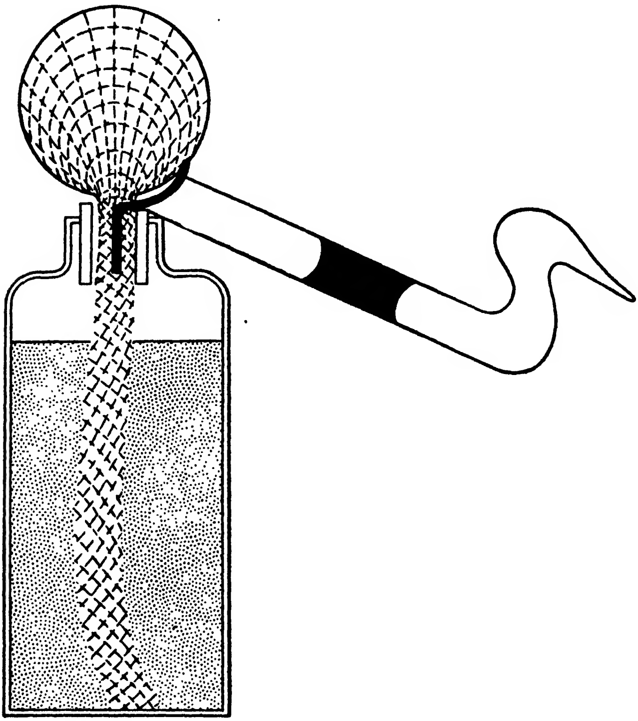


Fig. 15. Sketch of a dragoyle, showing the larger of the two glass bulbs covered with a cloth leading down through a *loose* rubber sleeve into a reservoir of water. The drop of colored liquid is about midway between the two bulbs, or halfway to a "beat." A stiff wire holds the glass part in position above the rubber sleeve.

DRAGOYLE

The dragoyle (Fig. 15) a few years ago was a novelty. It is, however, adapted for quick and easy reading; thus considerable data can be acquired in a short time. The details for making dragoyles are given in "The dragoyle as an ecological instrument" (*Ecology*, **12**:448–452. 1931) by F. C. Gates and R. L. Black. Basically the instrument depends upon the possibility of differential cooling of the larger of two bulbs in a partial vacuum in which

a liquid can act as a seal. When held at the proper angle, *i.e.*, with the tube between the two bulbs at an angle of about 25 degrees above the horizontal, and the larger bulb—which is uppermost—kept moistened with a wick, as the large bulb cools through evaporation, the liquid seal moves along through the connecting tube from the vicinity of the small bulb into the large bulb. This permits immediate equalization of pressure and temperature, following which the liquid flows down the tube to make another seal close to the small bulb. The number of movements or beats per minute is recorded. The instrument is sensitive, not only to the amount of moisture in the air, but also to the amount of wind and sun shining on it, as well as to temperature, so that while it does indicate relative humidity, it is not so close a measure of it as the psychrometer. The advantage of the dragoyle is that the instrument is small, can be carried around easily, read easily and quickly, and can be placed in small places. The disadvantages are that unless it is calibrated the readings are relative, are lost as soon as they are made, and are subject to variation with careless handling. With calibration, *i.e.*, ascertaining the number of beats the dragoyle shows while a free-water surface is evaporating a known amount of water, the readings may then be calculated as evaporation of so many cubic centimeters per minute. In the case of the instruments used at the University of Michigan Biological Station, the figure is 0.000608 cubic centimeters per beat.

Exercise 43. Dragoyle

In accordance with directions supplied make a dragoyle.

Hold the instrument at least a foot in front of you in the place selected for a reading and count the number of beats for one minute, or for two minutes, and record half that number. Move to another place and repeat.

Go to as many different situations as possible within a short period of time and count the number of beats per minute in each.

Profiles of ravines and transects through various types of vegetation may be made and plotted on cross-ruled paper. A dragoyle may be read at stated times each day in a given place and the results plotted

Exercise 44. Climate

Obtain temperature, humidity, and precipitation records from the local weather bureau, *Bulletin Q* of the U.S. Weather Bureau, or from the 1941 Yearbook of the Department of Agriculture, entitled "Climate and Man," and plot for your locality and others, as directed, such factors as: maximum temperatures, minimum temperatures, mean temperatures by days, weeks, or months; precipitation totals by weeks or months; average relative humidities for different times of day and for different seasons as directed.

Compare the hourly changes of relative humidity with those of the air temperature.

Compare such curves (graphs) for different places selected to show different types of climate.

Droughts may be expressed in the manner of Thornton T. Munger's "Graphic method of representing and comparing drought intensities" (*Monthly Weather Review* for November, 1916) by erecting right-angle triangles with bases on the *X* axis or abscissa covering the number of consecutive days in which the rainfall is below the stated figure, while the height expressed on the *Y* axis or ordinate is likewise the number of days of drought. To give a satisfactory impression the ordinate scale should be at least twice that of the abscissa scale. During years of normal rainfall, a saw-toothed figure is presented, but in times of drought, high, irregular teeth will be shown. The amount that should form the basis of the teeth may be varied. In the article cited 0.05 inch was suggested, but if the study concerns agricultural value 0.25 inch might be chosen, since it is usually considered that rainfall must be at least that amount in a day to be of importance.

Keep in mind that all these figures were not obtained in the actual habitats of the plants studied, so apply only in a general way.

SOIL

Hydrogen-ion Concentration[1]

Whenever detailed studies of an area are made it is necessary to know the chemical reaction of the soil water, that is, the pH.

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 230–233; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 165–178.

In accordance with the ionic theory, in aqueous solutions the concentration of the hydrogen ions and the hydroxyl ions are directly related. The concentration of the un-ionized water in dilute solutions is nearly constant. For that reason the product of the two ion concentrations has a nearly constant value (10^{-14} units at 25°C), whether the solution is acid, neutral, or alkaline. In neutral solutions there are equal concentrations of hydrogen ion and hydroxyl ion, or 10^{-7} gram-ions per liter at 25°C. It is customary to express this condition at pH7. In other words, pH is the symbol for the logarithm of the reciprocal of hydrogen-ion activity. The values indicate degrees of alkalinity or acidity. In an acid solution the hydrogen ions are in excess and the pH values are lower than 7, *e.g.*, pH6, pH5, etc. In an alkaline solution the hydroxyl ions are in excess and the pH values are greater than 7, *e.g.*, pH8, pH9, etc.

The hydrogen-ion concentration is most accurately determined by measuring the electrical conductivity of the liquid to be tested in a laboratory. There determinations may be carried to one or two places of decimals. These determinations serve as the standard against which all other methods must be compared. Another laboratory method is by colorimeter comparisons with a battery or series of colors set up for different values. These batteries need to be made up with a series of dyes which have different points of reaction.[1] The soil solution is properly prepared in a similar tube, the dye added, and its color compared with the set of standards. This colorimetric method, if not too unwieldy, may be taken into the field and under suitable conditions used to advantage there. This is important if the sample does not hold its hydrogen-ion concentration after collection. Another colori-

[1] The dyes most serviceable as indicators for ordinary use are

Indicator dye	pH range	Color change
Bromphenol blue.	3.0–4.6	Yellow–blue
Bromcresol green.	4.0–5.6	Yellow–blue
Chlorphenol red.	5.2–6.8	Yellow–red
Bromthymol blue.	6.0–7.6	Yellow–blue
Phenol red.	6.8–8.4	Yellow–red
Thymol blue.	8.0–9.6	Yellow–blue

metric method employs colored papers. The material is mixed with proper dye solution in accordance with definite directions and the color compared. Still another colorimetric method utilizes Heide's pH-meter, in which the standard colors are baked in a porcelain plate along the edge of a channel in the center. The material to be tested is mixed with the proper dye mixture, allowed to react for about a minute, and then the liquid shaken through the channel and the color compared with those on the sides.

NOTE: By the electrical method, hydrogen-ion concentration may be determined to tenths and hundreds of pH units. In the various colorimetric methods determination is generally in whole units or half units, only rarely to tenth units. However, when one considers that plants are adaptable, often over wide ranges of pH, determinations in general ecological work should be made in whole pH units, only rarely to half units.

Remember that individual pH's differ from each other by jumps of power units, so that pH5 is 10 times as acid as pH6, and pH4 is 100 times as acid as pH6, etc. There are on the market several simple devices which make the rough determination of pH in the field quite easy, but it should be stated clearly that in so far as plants are concerned, the sensitivity to pH is far less than it was originally thought to be. There are many plants which will grow only in an alkaline medium, many others in an acid medium, a great many which grow in both. For some the pH may be shifted one way or the other to a considerable degree. As an example of economic application, some agricultural plants which will grow in either acid or alkaline mediums yield more in one than in the other. In determining the pH relations of plants it is customary to loosen the soil around the plant, lift the plant, and shake off some of the dirt closely associated with the roots. This dirt is moistened with the dye mixture according to directions and the color change is read. To prepare for the quinone electrode electrical determination, dirt is shaken from the roots into a small dish and the proper amounts put in the proper solutions for use in determining the change of electrical resistance in the circuit. The circuit when calibrated will read to actual pH's.

Exercise 45. Determination of Hydrogen-ion Concentration, pH[1]

With the kit available, in accordance with the directions accompanying, test the pH of

The soil around the roots of various plants.

The soil water, or water of streams, rain, etc.

The juice of various plants, insects, etc.

The soil around the roots of a given kind of plant in various situations.

If the area under consideration is diverse, make a pH map of the area.

Soil Water Content[2]

The amount of water present in the soil is an important factor in the life of plants growing there. The smaller the size of the soil particles, the larger the amount of water which may be held in the soil, and also, the larger the amount of water that plants cannot take away from the soil. An excess of rainfall either runs off on the surface of the ground or sinks in and seeps out in springs at a lower level or is added to subterranean water. Not all of the water remaining in the soil is available to plants. This can be easily demonstrated by ceasing to water a healthy growing potted plant. As soon as the plant wilts down, take a sample of the soil from the pot, weigh, heat to dryness, and reweigh. The finer the soil particles, the greater is the amount of water held back from absorption by the roots of the plants.

To determine the amount of water that the soil can hold, take a cylinder of soil, with as little disturbance as possible, in a tube open at one end and closed with a porous plug or perforated plate at the other. Set this tube of soil upright and add water until it begins to drop through the soil. When dropping of water ceases, take a sample from the center of the tube, weigh it, heat it to dryness, and reweigh. The loss divided by the dry weight

[1] Snyder, E. F., "Methods for determining the hydrogen-ion concentration of soils," *U.S. Dept. Agr. Cir.* 56. 1928.

[2] Cf. Weaver and Clements, *op. cit.*, pp. 199–215; Braun-Blanquet, *op. cit.* (tr. and rev. by Fuller and Conard), pp. 211–218.

will give the percentage of water content based on the dry weight. To obtain the water content in any given soil, take a known weight of fresh soil as a sample, heat it to dryness in an oven at a temperature of 100 to 105°C. The amount of water lost, divided by the dry weight of the soil, will be the percentage of water based on the dry weight.

Another method which may be used involves the use of soil points. Soil points are blocks of wood whose initial weight has been determined, after which they are kept in watertight containers or are weighed immediately before using. These blocks of wood are driven into the soil at the location desired, allowed to remain there the better part of a day or more, after which they are removed and reweighed. The gain (or loss) in the weight is a measure of the soil moisture.

Bouyoucos has developed two other methods for determining soil moisture, which are much more rapid and can be carried on in the field. Both depend on high-purity alcohol to take the water out of the soil. In the one method the change in the specific gravity of the alcohol before and after contact with the soil is measured with special hydrometers (see *Soil Science*, **32**:173–179, 1931). In the other method the alcohol (methyl, ethyl or propyl) which has extracted the water from the sample is set on fire and dries the sample to constant weight (see *Soil Science*, **44**:377–383, 1937, and **46**:107–111, 1938).

Exercise 46. Soil Water Content

By one of these methods determine the soil water content of certain soils in selected areas, week by week throughout the season. Express in graphs or diagrams.

Mechanical Analysis of Soil

The size of the particles of soil determines the amount of water that the soil may hold against gravity and the amount of water left in the soil after plants have taken out all the water that their roots are able to get. Two systems of nomenclature are in use. That most frequently used in America is given below.

Size of Particles	Name
2 mm and over	Coarse gravel
1–2 mm	Fine gravel
0.5–1 mm	Coarse sand
0.25–0.5	Medium sand
0.1–0.25	Fine sand
0.05–0.1	Very fine sand
0.005–0.05	Silt
Less than 0.005	Clay

To conduct a mechanical analysis a weighed amount of soil is shaken through progressively smaller-meshed sieves. The amount retained by each sieve is determined and expressed as the percentage of the original weight of the sample. Sieves with round holes punched in the plate are to be preferred to sieves made with wires crisscrossing.

Exercise 47. Mechanical Analysis of Soil

Secure sufficient soil (2 to 10 pounds more or less) dry, weigh. Shake through sieves of known weight with progressively smaller holes. Reweigh each sieve with its catch of soil, subtract weight of sieve, and calculate as percentage of weight of original sample.

Soil Composition

In certain types of ecological work it may be necessary to ascertain the amount of certain chemicals present in the soil. While this is not usually done in beginning classes, should it be necessary to do so the standard chemical laboratory directions for the determination of such things as nitrogen, magnesium, calcium, phosphorus, potassium, etc., should be followed in the chemical laboratory.

Soil Horizons (Soil Profile)[1]

To determine the horizons or layers of soil it is necessary to dig a hole or a trench to the proper depth. The various soil horizons are shown in the accompanying diagram. Each of them may vary in depth with differences in soil. These characteristics determine the types of soil. Each of the layers may be subdivided; *e.g.*, in pine forests the A_{00} layer is the freshly fallen pine

[1] Cf. Weaver and Clements, *op. cit.*, pp. 189–199.

needles. A_0 is the pine needles which fell the previous year but which are not visibly decayed. The A_1 layer is that in which the pine needles have been on the ground two years or more and are

	A_{00}	Loose leaves and organic debris, largely undecomposed. Usually absent in grasslands.
	A_0	Organic debris partially decomposed or matted. Usually absent in grasslands.
Solum, the true soil	A_1	Dark-colored horizon, containing a relatively high content of organic matter, but mixed with mineral matter.
	A_2	Light-colored horizon, the region of maximum leaching.
	A_3	Transitional to B, but more like A than B. Sometimes absent.
	B_1	Transitional to B, but more like B than A. Sometimes absent.
	B_2	Usually deeper-colored horizon, representing the region of maximum accumulation. In grassland soils with a definite structure, but with a minimum of accumulated materials, and represents a transition between A and C. An accumulation of clay may or may not be present.
	B_3	Transitional to C.
	C	Weathered parent material. Occasionally absent where soil building follows closely on weathering. May include zones of accumulation of calcium carbonate in grassland soils.
	D	Underlying stratum. Hard rock, layer of clay or sand, which while not parent material may sometimes affect the overlying soil.

FIG. 16. A hypothetical soil profile showing the principal horizons. Not every soil is expected to have all these well developed, but some are present in every soil. The organic materials falling upon the soil are received and broken up in the A layer. Parts go into solution in rain water and are carried down into the soil with it or drain away with runoff. In the B layer is the accumulation of materials in solution from above and materials diffusing upward from C, the layer of parent material. (*Modified from "Soils and Men," Yearbook of the U.S. Department of Agriculture,* 1938. *See also the zonal soil map of United States in John E. Weaver and F. E. Clements, "Plant Ecology," 2d ed., p. 193, McGraw-Hill Book Company, Inc.,* 1938, *obtained from the U.S. Department of Agriculture.*)

visibly decaying through the action of bacteria or soil fungi and are mixed with mineral soil. A_2 layer is the layer of soil high in organic material, but subject to the maximum leaching by rain into the B level. The B horizon is that in which the plants, especially trees, have the majority of their roots and from which they get nearly all the minerals which are necessary for their development. It is less frequently divided into parts than the A layer, although it may be. The C horizon is that below the B

horizon and primarily is that which is unweathered or not yet weathered sufficiently to form the mineral basis of soil. In it there is little or no organic matter except as some roots of some of the plants may penetrate into it. This layer may be very deep but ends below in solid rock. In recording soil horizons it is best to set up a vertical column in which the various horizons and their subdivisions are set off on a linear scale. The pH of each horizon may be determined. Generally speaking, in forests the pH of the *A* layer is likely to be acid, the *B* layer may be, but the *C* layer may be slightly alkaline, depending upon various factors in the environment.

Exercise 48. Soil Profile

Dig a short trench 100 centimeters or more in depth and smooth off one side. Mark off the layers and sublayers with matches or bits of wood. Measure and sketch to scale. Scoop out a handful of soil in each layer and examine it for constitution, consistency, stickiness, organic material, pH, and water content. Chemical and mechanical analyses may be made later from samples taken and preserved in sealed jars.

Repeat for different situations, such as forest, grassland, sand dune, etc.

Profile of the Surface of the Ground

Particularly when studying sand dunes the making of profiles of the surface of the ground is an essential procedure. The same methods may be employed for profiles in any study but are particularly significant in the case of dunes. The simplest method is measuring with a set of levels. All this requires in the way of instruments is a pair of stout measuring sticks 1 or 2 meters long, graduated in 10-centimeter intervals, and a level. A simple carpenter's level or a photographic level serves, or, in their absence, a bottle partly filled with water may be used. *Procedure:* If the initial position is in a depression, one rule is held vertically at the point of starting, the other held level touching the ground so that a definite distance forward is measured from the vertical stick. The level should be placed on the horizontal stick and the rear end gradually raised until it shows level. The reading of elevation is then taken on the vertical

stick. This is then moved to the forward end of the horizontal stick and the latter is moved ahead, elevation measured, and the operation repeated. These directions are repeated until the end of the profile is reached. If, however, one starts at the highest point, the reading is made in the reverse way. The notes are most conveniently recorded in the form of the following table:

Number of point or station	Distance moved forward	Change of elevation	Remarks

Sometimes it may be desirable to mark the station or point number on the land as the starting point of a divergent profile. The distance moved forward may always be the same, or it may vary with the situation. In plotting subsequently there is every advantage in having this distance the same. The differences up should be preceded by a plus sign and the differences down by a minus sign. Remarks may include vegetation, presence of rocks, dead trees, or other landmarks, depending on the type of work one is doing.

In sand-dune work a profile on the 1 to 1 basis will give a real section of the dune. If the profile is suitably selected, it will show clearly the gentle building-up slope and the steep lee slope. If the lee slope is so steep that a slight touching will set the sand rolling, then the profile will show the angle of repose. If slopes are not that steep, sand may be pushed up until it does begin to roll, whereupon the angle of repose may be determined.

If a profile crosses bodies of water at right angles to a stream or the surface of a lake, the water surface is a constant figure. Measurements should therefore be taken from the water surface to the bottom. If, however, a profile runs up or down a stream, the same methods as on land would apply, except that transits are generally much simpler to handle than measuring sticks.

Profiles may be taken in other ways.

Hand-level Method. Where a hand level is used, the observer sights through the instrument and sees, through half of the circle, objects in the landscape which may be brought into sharp focus by adjusting the sleeve. On the other half of the

circle he sees the reflection of the bubble in the level on the top of the instrument. By raising or lowering the end of the instrument with reference to his eye, the bubble apparently is made to go up or down. The reading should be taken when the bubble is evenly divided by the central cross hair. The observer sees the place in the landscape which is at the height of his eye above the ground. Noting carefully, he then walks to that place and makes another reading. Distances between readings may be obtained by pacing, or they may be measured by tape or chain. The data then consist of similar items as given above except that in this case the distance moved will be very irregular, while the difference in elevation will be the same in each case. The advantages of the method are the quickness in getting difference of elevation of hills where the distance is not necessary and the fact that it can be done by one person working alone. If the changes of elevation are so small that the distance one has to go between units is too great to see clearly, the method should be modified by having a partner who carries a stadia rod. On this rod the location of the eye height may be made at any conveniently seeable distance from the observer by subtracting or adding the known eye height of these smaller increments or subtractions may be calculated and recorded.

Exercise 49. Surface Profile

Make a profile along a line as directed, preferably over a sand dune. Record the data as indicated above.

Plot on cross-ruled paper using different scales for X and Y axes. Contrast the resulting profile. Which scale gives the best impression to the eye?

NOTE: Profiles show changes in elevation of the surface of the ground, while soil profiles distinguish layers in the soil down from the surface in a given place.

PEAT STUDY[1]

One of the promising fields of work which seek to give the details of the history of the vegetation is work with peat. The

[1] Cf. also Weaver and Clements, *op. cit.*, pp. 77, 184.

basis of this work is the fact that peat is a good preservative and plant parts, particularly pollen grains, are often well preserved in it. As new peat is formed each year and pollen showers in definite periods, layers of pollen intersperse with layers of peat. Getting year-by-year layers is usually impossible on account of the wetness of the terrain in the United States and Canada, but when taken in units of depth, pollen counts yield data which appear to be significant. As peat is formed it is quite loose and composed principally of growing plants, generally certain mosses as Sphagnum or Hypnum, certain sedges, especially species of Carex, and various other plants. The annual layer of moss or Carex peat is thickest in the year of its formation. During the following years, as the softer tissue disintegrates, the depth of the annual layer dwindles considerably. Depending upon the situation, an inch of peat laid down in one year may compress to about half an inch in the second year, to about a fifth of an inch in the third year, and approximately a tenth in the fourth year, and reaches its ordinary minimum within a period of 5 to 10 years. After that the shrinkage is less and can with difficulty be ascertained.

Sampling peat in high bogs, such as are present in eastern North America near the seacoast, is easier, as only a trench need be dug from the side of which specimens are scooped out at whatever intervals are desired.

The specimens are treated with potassium hydroxide, alcohol, boiling water, or basic alcohol, and colored with 3 per cent gentian violet stain. Centrifuging is often employed, but straining damages pollen grains less while still removing debris. Following treatment, a portion of the material from a known area is spread out on a slide in water or glycerin jelly, cover glass put on, and the pollen grains counted. Usually, however, the count of a selected number of pollen grains is made—100, 200, or 300—against the identification of the pollen grain. If possible, record the species, but quite frequently one has to be content with no more than the genus of the pollen grains if even that can be recognized. If all pollen grains were preserved, a good account of vegetative history could be figured out. However, since only certain of the grains showering onto the bog are preserved, no history drawn up is complete. The figures obtained are usually

expressed in percentages of the different genera or species at the different levels. The percentages from the various levels are plotted on cross-ruled paper and by a study of the changes one gets an idea of the changes of vegetation types. This work can only be done in bogs, since swamps support a bacterial population which breaks down the pollen grains. On land the work fails also because the pollen grains dry up and are ground into the earth and leave no record. Most American bogs are wet and the various rains are bound to bring about a certain amount of mixing of the various pollen showers. Because of this mixture it is not advisable to take samples at too close intervals. If one has any means of telling how much peat is laid down in a given time, dating offers possibilities. Dating in several Ohio bogs indicates about 300 years for a foot of peat. In northern Michigan bogs it would seem that it does not exceed 100 years. Such differences can be expected in different climates.

For the wet American bogs a different type of sampler must be employed, since ordinary borers cannot be satisfactorily used in water. The Davis borer is the one most frequently used. In the Davis borer a plunger inside of a sleeve permits one to push the sampler down to any desired depth, then with a twisting pull the plunger is pulled back from the end and catches. Then a pushing of the whole sampler down 6 inches should yield a cylindrical sample of material. This can then be pulled up to the surface, the plunger released, and the sample pushed out of the sleeve into some suitable container. If the sampler has to come up through water, unless the sample is firm it will not be held, nor can any soggy wet sample be obtained by this method. Since many bogs are so wet that no samples can be obtained with the Davis borer in the first 6 to 10 feet, considerable recent record is lost. Likewise, the question of how much the sample has been compressed is usually unknown. It has been deemed most satisfactory to take these samples at intervals of a foot or 30 centimeters in general, or where feasible at 15 centimeters or 6 inches. The advantage of the Davis borer is that when samples are gotten they are definite cylinders which can be sliced. The outstanding disadvantage of the Davis borer is that if any sand gets into the sampler it must be brought up and cleaned before any samples

can be secured. Even a few grains of sand between the plunger and the sleeve hold it together so that no movement in peat will take place. Even when brought up, it may take considerable force to get movement of the plunger and the sleeve. Sand cannot always be avoided and any sand that does get into the instrument gradually wears away both the plunger and the sleeve, thus wearing out the instrument. New instruments may give trouble by having the sleeve clamp down on the plunger below the surface of cold bogs.

A modification of the Davis borer has been made by Thomas Cobbe and others, which works on the principle of pushing down to the desired depth a closed system which has a projecting scoop. When one is ready to make a sample, a twisting movement opens a central box, a further twist scoops the material in from the side, a reverse twist closes the box, and the sample is brought to the surface. For this type of sampler it is best to cut a hole down to near the sampling area so as not to have the roots and parts of living (or recently dead) plants entangled in it. A casing may of course be put down for part of this depth. The advantage of the sampler is that samples that have sand in them may be taken; in fact, the sampler will make sand samples.

Suction and pumping methods may be employed but both are too cumbersome for general classwork. In all cases the samples are taken to a laboratory for study or they may be put in simple preservatives such as 2 per cent formaldehyde, or sodium benzoate. It is best to keep the samples moist. About 1 cubic centimeter of the sample is shaken up with water or other reagent and may be heated with potassium hydroxide to dissolve away as much of the soft material as possible, then centrifuged to collect the grains, after which they are sampled from the centrifuged material, or they may be mixed up with water and brought to a certain volume, thoroughly shaken up, and an aliquot part taken for counting. The counting may be made either on an area basis, a volume basis, or a certain number of grains may be counted. The percentages are always based on a certain number of grains being counted, but the other counts give an expression of density of volume. A good deal of recent work in pollen counting has been carried on in eastern United States and the student may

be referred to many papers in the *American Midland Naturalist* and in particular to the *Butler University Botanical Studies.*

Exercise 50. Peat

With a Davis peat sampler obtain a series of peat samples from each 15 or 30 centimeters from the surface of the bog and describe each in terms of consistency, color and composition. Prepare microscopic slides and identify, as far as possible, the kinds of pollen grains. Determine the percentage of each kind present, either by counting the number in a known amount of material or by counting and naming the first one or two hundred from each sample. Construct a diagram showing the proportions of different kinds of pollen grains in each foot below the surface. Consult the following:

Cain, S. A., "Pollen analysis as a paleoecological research method," *Bot. Rev.*, **5**:627–654. 1939.

Erdtmann, G., "An introduction to pollen analysis," Chronica Botanica Company, Waltham, Mass. 1943.

Sears, P. B., "Common fossil pollen of the Erie Basin," *Bot. Gaz.*, **89**:95–106. 1930.

Wodehouse, R. P., "Pollen grains," McGraw-Hill Book Company, Inc., New York. 1935.

CHARACTERISTICS OF COMMUNITIES: A SOCIOLOGICAL SUMMARY

As an outline to summarize the possible lines of work that may result from a study of a plant association or plant community, the accompanying table, drawn up by Stanley Cain, serves to call attention to the more important items.

All of the items included will not be investigated by students in beginning classes. They will, however, serve as a goal toward which future work may lead. Each item will require a previous accumulation of data the proper parts of which will be utilized in filling out the table. Most of these data will have been acquired in the quadrat, tree counting, and transect studies (Exercises 1 to 25). Polygraphs (Exercise 27) may then be constructed for as many items as desired and comparisons made between similar polygraphs constructed for other associations.

Sociological summary	Concepts relating to the species composing a plant community														
	I. Organization											II. Synecology		III. Genetic sociology
	A. Analytic								B. Synthetic					
	1. Quantitative				2. Qualitative									
Floristic list	*a.* Abundance 1–5	*b.* Density 1–100	*c.* Dominance 1–5	*d.* Frequency 1–5	*a.* Sociability 1–5	*b.* Vitality 1–3	*c.* Periodicity 1–6	*d.* Stratification 1–4	*a.* Presence 1–5	*b.* Constance 1–5	*c.* Fidelity 1–5	*a.* Life form 1–10	*b.* Leaf size 1–6	Dynamic behavior 1–5

An explanation of the several items in the table follows. For an extended treatment reference should be had to publications by Cain,[1] Braun-Blanquet and Pavillard,[2] and Chaps. III and IV of "Plant Sociology."[3]

QUANTITATIVE ANALYTIC CONCEPTS

Abundance. Abundance is an appreciation of the relative number of individuals of each species entering into the constitution of the plant population of the territory under study. A scale of five degrees of abundance was suggested by Braun-Blanquet and Pavillard (1928) as follows:

A1—species very rare in the community

A2—species rare in the community

A3—species not very abundant in the community (= common)

A4—species abundant in the community

A5—species very abundant in the community

For the third category *common* might be a more satisfactory word to use.

Density. The determination of density involves measurement of the amount of space that the individuals of each species occupy in comparison to the total space under discussion. Such exercises as 2 and 3 furnish the data for this figure. Expressions such as "individuals per square meter" or "per acre" are good ways to state density.

Dominance. Dominance is primarily concerned with the control over the environment involving numbers of individuals, or the extent—the volume—covered or occupied by individuals of each species. The highest layer or stratum is generally the one in which the dominance is exerted. This is true of forest associations but in desert areas the primary dominance is obtained by the root system rather than the aboveground parts. Where many strata are present the value should be obtained in

[1] CAIN, STANLEY A., "Concerning certain phytosociological concepts," *Ecol. Monog.*, **2**:475–508. 1932.

[2] BRAUN-BLANQUET, J., and J. PAVILLARD, "Vocabulaire de sociologie végétale," 3d ed., pp. 1–23. 1928.

[3] BRAUN-BLANQUET, *op. cit.* (tr. and rev. by Fuller and Conard).

each layer separately. For layers below the upper it is questionable whether the word "dominance" should be used. If five categories are set up, the following are suggested:

Do. 1—species covering 1 to 5 per cent of the surface
Do. 2—species covering 6 to 25 per cent of the surface
Do. 3—species covering 26 to 50 per cent of the surface
Do. 4—species covering 51 to 75 per cent of the surface
Do. 5—species covering 76 to 100 per cent of the surface

Frequency. Frequency is the term used to express the uniformity with which the individual plants of a species are distributed throughout the community. It is a statistical idea which is obtained by studying a certain number of quadrats or sample plots spread as widely through the area as possible. The number of quadrats in which a species occurs, divided by the total number of quadrats taken and multiplied by a hundred, gives the frequency index. The frequency index is ordinarily a satisfactory method of expressing occurrence in an association, but if too few quadrats are taken it may not be a sufficiently accurate expression. A study of the number and size of quadrats necessary to give the best frequency index is an exercise in itself which will not usually be taken up in a beginning class. Frequency may be expressed in classes as suggested below:

Class A, F1—species in 1 to 20 per cent of the quadrats
Class B, F2—species in 21 to 40 per cent of the quadrats
Class C, F3—species in 41 to 60 per cent of the quadrats
Class D, F4—species in 61 to 80 per cent of the quadrats
Class E, F5—species in 81 to 100 per cent of the quadrats

Or the actual frequency may be given in the last two classes. It is important to realize the essential distinctness of these concepts of the number of the area, or coverage, and homogeneity, which are often very much mixed up in ecological literature. Other terms are used by various authors but it is wisest to endeavor to have some numerical figure associated with each category.

QUALITATIVE ANALYTIC CONCEPTS

Sociability. The category of sociability has to do with the manner in which the species as individuals or in groups occur in

reference to each other in the given community. Classes of sociability are subject to a great deal of variation but the following five classes should help in standardizing the data. According to Braun-Blanquet and Pavillard the five classes are

Soc. 1—growing isolated
Soc. 2—growing in groups
Soc. 3—growing in numbers
Soc. 4—growing in little colonies
Soc. 5—growing in large colonies

Vitality. Vitality concerns the vigor and prosperity attained by the different species. Three classes are usually recognized as follows:

Vi. 1—plants germinating accidentally and not able to multiply

Vi. 2—plants with their life cycle incomplete but with vigorous vegetative development

Vi. 3—plants well developed and accomplishing regularly their complete life cycle, flowering and fruiting

Periodicity. This refers to the different aspects of the community during the year. The aspect may have to do with leafiness or flowering or fruiting, etc., and a different table set up for each, or the data may be organized with lines widening to show greater abundance or presence and narrowing to show diminished abundance and stopping to show absence. The principal classes I find necessary are

Pe. 1—prevernal
Pe. 2—vernal
Pe. 3—estival
Pe. 4—serotinal
Pe. 5—autumnal
Pe. 6—hiemal

Stratification. This refers to the superimposed layers of vegetation. The number varies in different types of vegetation. In the table the number of layers should be indicated. In most of our forests the four following strata can usually be distinguished:

St. 1—moss-lichen stratum, or ground stratum
St. 2—herbaceous stratum

St. 3—shrubby stratum

St. 4—tree stratum

A tree sapling in the herbaceous stratum is "passing through" it. It may then be termed a *transgressive*.

SYNTHETIC CONCEPTS

Presence. This concerns the degree of regularity with which species reoccur in different examples of an association. In a beginning course more than two or three examples of the same association are not likely to be studied, consequently this category will usually not be satisfactorily handled. If the same association is studied over a considerable area, one may find the following five classes useful:

Pr. 1—species found in 1 to 20 per cent of the concrete examples of the association studied

Pr. 2—species found in 21 to 40 per cent

Pr. 3—species found in 41 to 60 per cent

Pr. 4—species found in 61 to 80 per cent

Pr. 5—species found in 81 to 100 per cent

Constance. An expression relative to the presence of species in different examples of an association, constance is based on the species in a unit area in each association rather than in the entire extent. This small area should, however, be sufficiently large to give a representative expression. Constance is usually divided into five classes each of 20 per cent, or if ten classes are recognized ten classes each of 10 per cent. The basic idea might be expressed as done by Romell (1925, cited by Cain), "Homogeneity consists of a *repetition of variations*, sufficiently frequent on a given surface, in the composition of the plant cover."

Fidelity. Fidelity is a measure of the extent to which a species occurs exclusively in a single kind of plant community. It is also spoken of as exclusiveness. Five classes are recognized by Braun-Blanquet and Pavillard as follows:

Fi. 1—strangers, species appearing in a plant community accidentally

Fi. 2—indifferents, species growing more or less abundantly in several groups

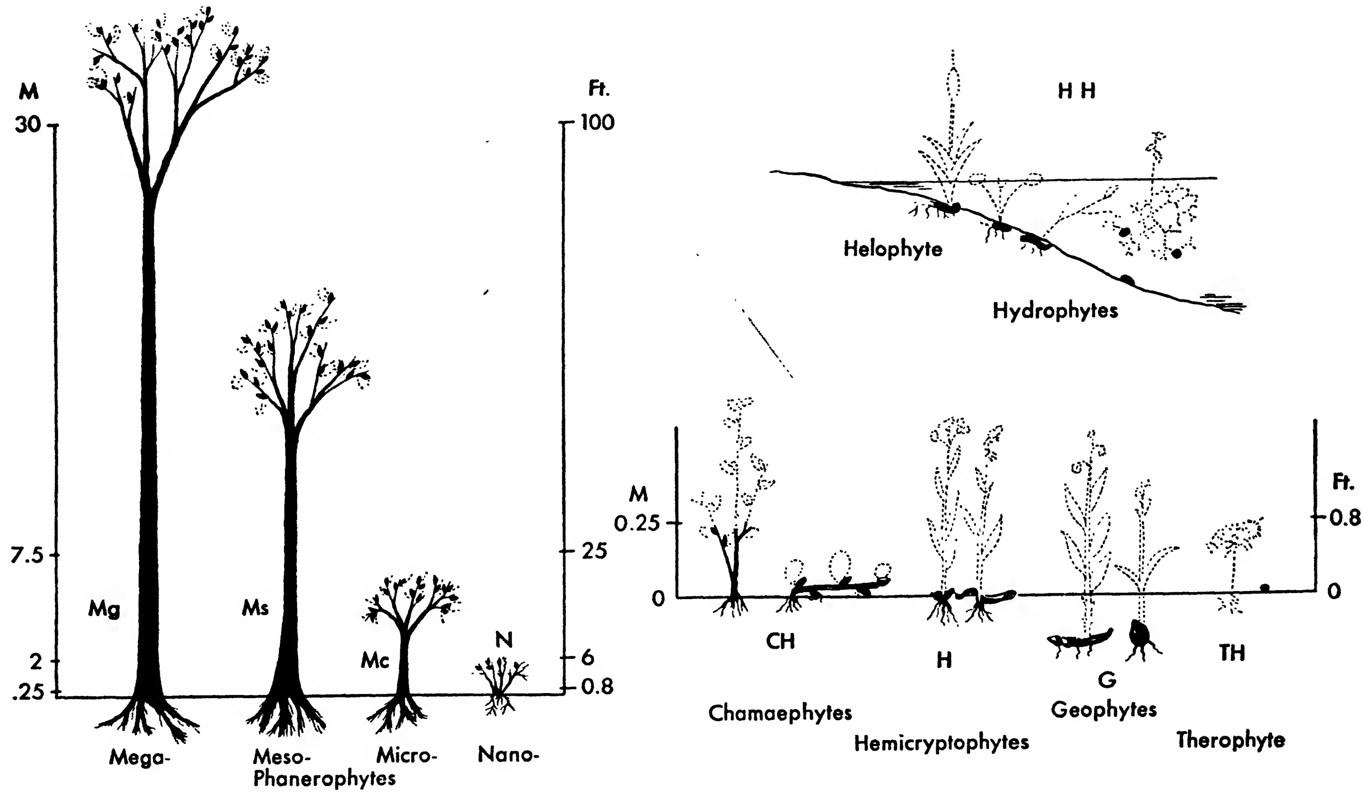


Fig. 17. Raunkiaer life forms. Diagrams to show the position of the overwintering bud (seed in the therophytes) relative to the surface of the ground.

Fi. 3—preferants, species existing more or less abundantly in several groups; preferring, however, a definite group

Fi. 4—electives, species found especially in one group but met with, although rarely, in other groups

Fi. 5—exclusives, species related almost exclusively to a definite group

Species of fidelity classes from 3 to 5 are considered the characteristic species or the species of narrowest ecological tolerance.

FORM CONCEPTS

RAUNKIAER LIFE-FORM CLASSES

There are a few systems of life-form classes, but that set up by Raunkiaer has much to recommend it, although without question some of the conclusions which have been drawn from it are hardly tenable. Raunkiaer used primarily the position of the highest perennating or overwintering bud to set up several classes. In addition to these, plankton and microscopic organisms in the soil and parasites form other classes.

In his own writings, Raunkiaer recognizes several subdivisions of some of the life forms, but here are given only those that have proved particularly useful in field work (Fig. 17). To make certain comparisons possible, Raunkiaer set up a "normal spectrum." After assembling representative floras from the various parts of the world, he determined the percentages of the different life forms, designating this as the normal spectrum. One may then, for instance, consider the prairie as a hemicryptophytic region, since the prairie has 55 to 60 per cent of hemicryptophytes, more than twice the normal spectrum.

Exercise 51. Raunkiaer Life Forms

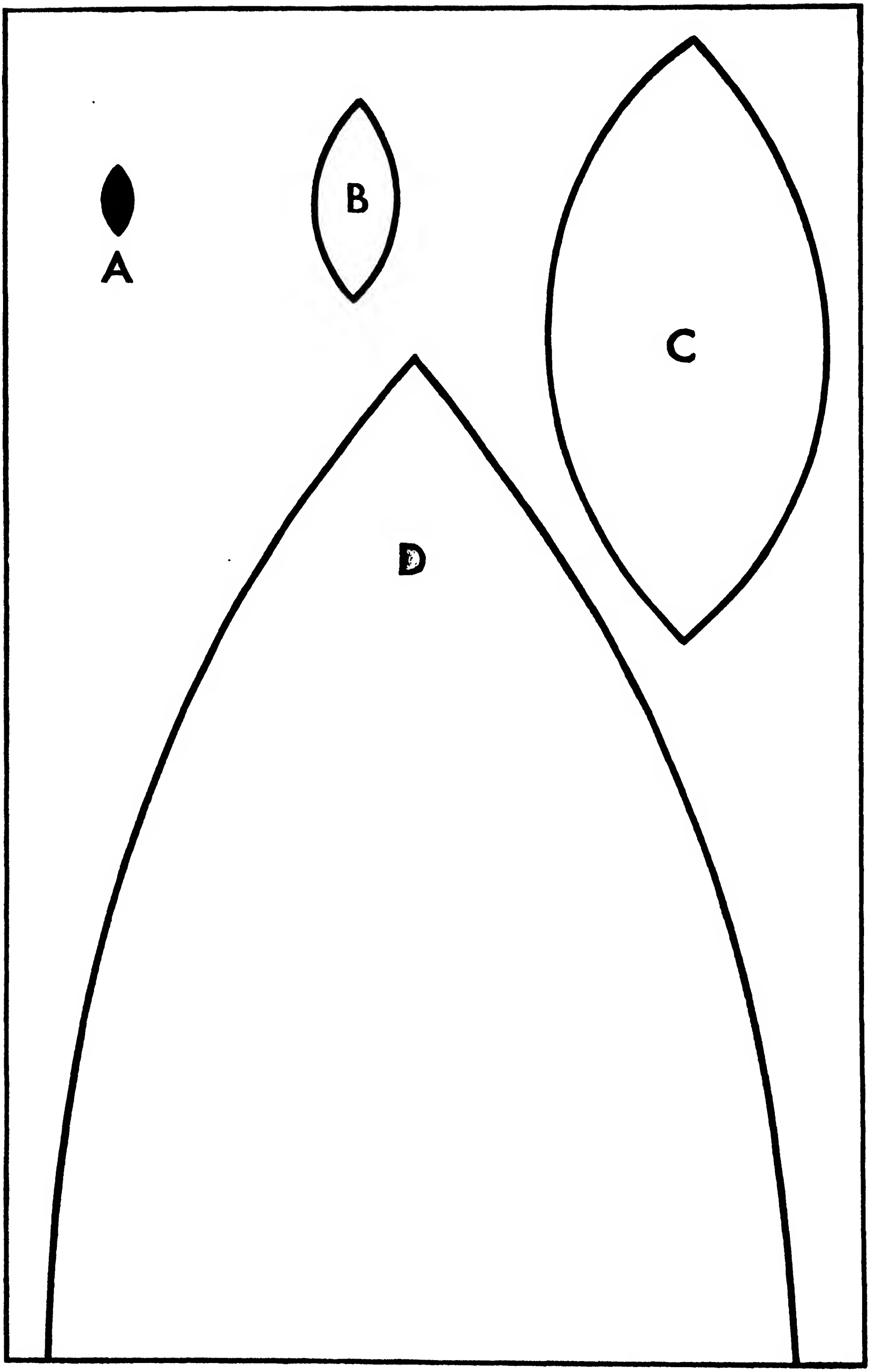
Determine the life forms of from 50 to 100 species assigned, or determine the life forms of the plants in an association or in a given area, and tabulate. Compare with the normal spectrum.

RAUNKIAER LIFE FORMS*

(Based mainly on the position of the highest perennating buds in relation to the surface of the soil)

Normal spectrum	Abbreviation	Life forms
2	S	Stem succulents
3	E	True epiphytes
		PHANEROPHYTES [highest perennating buds between the limits indicated]
8	Mg	Megaphanerophyte—30+ m (100 ft+)
	Ms	Mesophanerophyte—7.5–30 m (25–100 ft)
18	Mc	Microphanerophyte—2–7.5 m (6–25 ft)
15	N	Nanophanerophyte—0.25–2 m (0.8–6 ft)
		CHAMAEPHYTES [perennating buds 0–0.25 m (0–0.8 ft)]
9	Ch	Chamaephytes
		HEMICRYPTOPHYTES [perennating buds *in* the surface layer of the ground]
26	H	Hemicryptophytes
		CRYPTOPHYTES [perennating buds fixed distances *below* soil surface]
4	G	Geophytes [fixed distance below ground] rhizome geophytes stem tuber geophytes bulb geophytes root tuber geophytes root geophytes
2	HH	Helophytes [cryptophytes with perennating buds on rhizomes under water or in saturated soil, but aerial stems also present] Hydrophytes [both buds and stems protected by water]
		THEROPHYTES
13	Th	Therophytes [overwinter as seeds] (includes annuals, winter annuals and biennials, the annuals overwintering every winter as seeds, the winter annuals and biennials alternating as hemicryptophytes or rarely chamaephytes their first winter and as seeds the next winter)
100	Bien.	Biennial

* Modified; for detail consult C. Raunkiaer, "The Life Forms of Plants and Statistical Plant Geography, being the collected papers of C. Raunkiaer," Oxford University Press, New York. 1934. In a modified form in Braun-Blanquet, J., "Plant Sociology" (translated and revised by G. D. Fuller and H. S. Conard), McGraw-Hill Book Company, Inc., New York. 1932.


A
B
C
D

RAUNKIAER LEAF-SIZE CLASSES

Raunkiaer also set up classes of leaf sizes (Fig. 18) which have proved to be useful in classifying associations. Leaf sizes are conspicuous, significant, and rather easily determined. They may be included in the classes tabulated below which are as follows. The classic representation of each of the classes helps greatly and is consequently included.

Class 1—Leptophyll, 25 sq. mm. (0.000025 sq. m.)

Class 2—Nanophyll, 9×25 sq. mm., equals 225 sq. mm. (0.000225 sq. m.)

Class 3—Microphyll, $9^2 \times 25$ sq. mm., equals 2,025 sq. mm. (0.002025 sq. m.)

Class 4—Mesophyll, $9^3 \times 25$ sq. mm., equals 18,225 sq. mm. (0.018225 sq. m.)

Class 5—Macrophyll, $9^4 \times 25$ sq. mm., equals 164,025 sq. mm. (0.164025 sq. m.)

Class 6—Megaphyll, larger than Class 5.

Before placing leaves in size classes, classify them as to character: aphyllous, evergreen, or deciduous; or simple or compound.

Exercise 52. Raunkiaer Leaf-size Classes

Determine the leaf-size class of from 50 to 100 plants assigned, or determine the leaf-size classes of the plants in an association, or in a given area, and tabulate.

GENETIC SOCIOLOGY

DYNAMIC BEHAVIOR

The dynamic behavior of plants is the only one of the items that applies to individual species. Five classes have been set up

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FIG. 18. Leaf size classes. (*After Raunkiaer.*) Diagram for use in rapid determination of the class size of a leaf. The figures show the boundaries between the individual classes, thus:

Less than A = leptophyll
Between A and B = nanophyll
Between B and C = microphyll
Between C and 2 times D = mesophyll
Between 2 times D and 8 times the size of the diagram as bounded by the black line = macrophyll
More than 8 times the size of the diagram as bounded by the black line = megaphyll.

sion. The most likely places occur around lakes and bogs. Less likely places may be found along rivers, but here succession may proceed for a few years normally and then be overthrown by floods or erosion. While this is nature, it adds difficulty to setting up a study of succession. Successional studies in the prairie and in mountain areas may be set up but it is usually only a lucky guess whether they will turn out to be all that was expected. Other types of succession may be seen following the abandonment of cultivated land or areas greatly disturbed following catastrophe, either natural or man-made.

Series (seres) of associations with successional relationships between them are grouped as follows:

Feralarch (natural series)	xerarch—series from dry or sandy land to mesophytic conditions on loamy lands hydrarch—series from water to dry land
Hemerarch (series connected with human activities)	series following cultivation, abandonment and other human activities, tending ultimately toward restoring the natural vegetation

While the teacher becomes accustomed to thinking in terms of succession, the student new to the work not infrequently has difficulty in this type of thinking until he has had a fair amount of ecological experience.

INITIATING SECONDARY SUCCESSIONS

(See also Exercise 11, Denuded Quadrats)

One of the most feasible ways of studying some of the mechanics of succession is to set up conditions that will result in secondary successions. Some of these will give results within one growing season, but if two or three years are available so much the better. The simplest form of all is to plow up the plot of ground and smooth it off and record what comes in. At the same time a study of the weeds of the vicinity should be made. Whatever is on the ground may be cut at the surface without turning over any of the soil, or the top inch or 2 or 3 to 12 inches may be completely removed and what follows recorded. A definite plot may be burned over lightly or thoroughly and studied before burning and subsequently. A piece of cultivated ground

may be abandoned and records taken of what happens. The removal of any buildings, sidewalks, concrete slabs, or the abandonment of a railroad spur all furnish possible sites for the observation of secondary succession. The main advantage of secondary successions is that they take place promptly as a rule and give a chance for some study during the same season that they are made. The disadvantage is usually that only weeds are concerned and very seldom does the succession have a chance to go to completion without interruption.

FIRE

A study of the effects of fire is of great importance, especially in forests and grassland. Fires may be designated as crown or ground fires. Crown fires burn out the tops of the trees but of course do damage to the ground also. A severe fire consumes the trees as well as the plants on the ground. Fires in grassland, if there is not a great accumulation of material, burn rapidly over an area and heat up the ground very little, generally not sufficiently to destroy seeds that are but a small fraction of an inch in the ground. If there is an abundance of vegetation to burn, however, so that the fire may be held for a longer time at one spot, the seeds in the upper part of the ground will also be burned up and excessive heating is possible down into the ground itself.

In experimenting with burning, the type of fire to be employed will vary, depending on the purpose of the experiment. Fires to be classified as severe are maintained for a considerable time in a small area with burnable material added if necessary. Light, sweeping fires are set with a wind in back of them to burn over an area quickly. A fire may merely sear the plants, as in some types of weed-eradication experiments.

The studies following are conducted with one or another of the quadrat methods, including particularly photographs and chart quadrats. They may be carried on at intervals as long as desired.

From such a study of fires set in different months of the year—*i.e.*, at different stages of plant development—one can learn when burning is least injurious or most injurious. The study of just such results forms the basis of recommendations for the control

of certain shrubs in grazing areas. For instance, A. E. Aldous ("The eradication of brush and weeds from pasture lands," *Amer. Soc. Agron. Jour.*, **21**:660–665. 1929) demonstrated that *Symphoricarpos orbiculatus* and *Rhus glabra* were best controlled by fires set in May.

Relation of fire to succession can be nicely shown in the southern states where the absence of fires for ten or more years is leading to the replacement of the pitch pines by hardwood species in many different areas.

Other good examples in which fires have played an important role in successions include the jackpine association in northeast United States, the Douglas-fir association in the Rocky Mountains, and the pine forests of the north Philippines.

Exercise 53. Burning

If feasible and desirable stake out areas for burning. Put a fire lane around the area and have a sufficient number of persons to keep the fire within the designated area. Before burning, take quadrat and tree counts, photographs, etc., to record the original conditions. After burning, photograph. After various lapses of time, restudy by the same methods as before and compare. Thus may be determined the length of time it takes to restore a similar appearance. For classwork, such a problem is started by one class and studied by subsequent classes.

Scatter a known number of seeds, not too small, over a bare area, pile grass loosely over the area and burn. Recover as many seeds as possible and subject to good germinating conditions to study the effects of the fire on seeds. The amount of material burned and the rate of burning may be varied in repetitions of this experiment.

INFLUENCES OF CIVILIZATION

Civilization is itself a form of ecological development. It furnishes many opportunities for the organization of class exercises, of which the following is but one. How does a path, a trail, or a road through an area of vegetation make itself felt on the natural vegetation? Such a problem may be investigated by taking continuous quadrats at right angles out from the trail,

etc. Inspection of these quadrats in comparison with a series taken in the natural vegetation will reveal how far from the road and by what species the disturbance is shown. The same results may be obtained through the use of the line-interception method. In northern Michigan, in the days when all vehicles were drawn by horses, the effect of the road was clearly visible for from 3 to 5 meters away from the road into the forest. More recent investigations following strictly auto traffic on the same roads before any "improvements" had been made showed that the influence was dwindling and hardly ever extended in excess of 3 meters from the road.

Exercise 54. Influences of Civilization

As indicated above, determine how far from a trail in a forest the effects of the trail may be demonstrated by taking continuous quadrats and noting in how many quadrats from the trail plants extraneous to the forest occur.

PLANTS AS INDIVIDUALS: AUTECOLOGY

When one studies in the field of static ecology or ecology of the individual, one takes up a given kind of plant and seeks to find out all that may be ascertained about that particular species, both under natural conditions and under controlled experimentation. For this purpose it is usually wise to select dominant species in various associations and investigate their characteristics, such as leaf sizes, leaf numbers, degree of branching, rate of growth of various parts, times of various functions, length of leafing, length of blossoming, number of blossoms, number of fruits, and points regarding the stems and roots. A bisect, *i.e.*, a side view of the whole plant, may be made by digging out a trench in front of a plant and picking out the roots, sketching them on cross-ruled paper as they are found. (Cf. Weaver and Clements, *op. cit.*, pp. 39–42.)

Plants may be transplanted bodily to different types of soil and their reactions learned; likewise, seeds may be planted under experimental conditions and set out under natural conditions. Experiments in physiology, involving such elements as the rate of photosynthesis, the amount of water given up, the amount of

water taken up from the soil, to mention a few, may be conducted on plants in natural situations and under experimental setups. (For additional experiments see pages 125 to 127.)

Exercise 55. Individual Plant Study

As such exercises are usually beyond the scope of elementary classes, no set directions are given here. Advanced students should by this time be able to set up experiments on individual plants upon which they wish to embark.

The subject of plant indicators may be brought in here for some advanced students. Every plant may be found to "indicate" something, but to be sure some are very much more important than others. (Consult F. E. Clements, "Plant Indicators," *Carnegie Inst. Wash. Publ.* 290. 1920.)

GROWTH OF TREES IN DIAMETER

The rate and amount of growth may be obtained directly, where it is possible to cut the tree down and measure and count the increments (often called rings) on the stumps. A core may be obtained by boring into the tree with a tree borer and the same results obtained without cutting the tree down. In using a tree borer one must remember that the center of growth is not necessarily at the center of the cylinder that the tree trunk appears to be. It may be necessary to average the results from a few cores. (Replace the core in the tree or seal the opening with wax to prevent infection by fungi.) If one has had reasonable experience with the trees of a given region, he may be able to estimate the age of the trees by inspection, but such a method may have a high percentage of error. If the trees are conifers and are not over about 30 to 35 years old, the location of the whorls of branches, counting from the top down, will give an estimate which may not depart from the actual age more than 5 to 7 years. Trees which have grown very close together so that lower branches have been self-pruned and the bark covers the scar will make it more difficult to determine ages.

Definite information as to dates of clearing or planting help to determine the age. Knowing the ages and the diameters, age-diameter tables may then be worked out and plotted. The

slope of the median line will be steeper, the faster the growth of the trees.

Exercise 56. Growth of Trees in Diameter

By one or more of the methods mentioned above, determine the ages of trees in a given area. Combine figures of age and diameter into an age-diameter table for each species selected. Plot these on cross-ruled paper, using ages as ordinates and diameters as abscissas.

ANNOTATED LISTS

Any general ecological study of a region will of necessity be accompanied by annotated lists—not only short lists in places in the manuscript where they are necessary, but usually also a general annotated list toward the end of the paper. The material may be in the form of an ordinary list or it may be expressed in tabular form. Species lists giving nothing but the scientific names of the plants are useful for many purposes, but when applied to ecology leave one without any sort of picture of the area unless he should be very well acquainted with the type of area or with the species present. For example, if on a list a person is confronted with a scientific name, such as *Gahnia javanica*, an unfamiliar plant, he has no clue to the growth form and consequently might think of a grass as a tree or vice versa, whereas, reading "*Gahnia javanica*, a sedge in the mossy forest of higher (Philippine) mountaintops," he knows that he is dealing with a secondary species in a forest. Thus from an annotated list of an area one may gain both a knowledge of the plants present and an insight into the appearance of the vegetation.

The Arrangement of Annotated Lists. The arrangement is somewhat of a personal problem, but two methods are in common use. One is to arrange the plants alphabetically by themselves or alphabetically under families which are alphabetically arranged. Or the families may be arranged in one or another of the systematic arrangements and the species under them arranged in alphabetical order, although a scientific order may be employed if one has good reason. There is usually an advantage in arranging the plants in families, particularly where the various members of a

family look much alike. However, advantages and disadvantages may be put forth for any arrangement that may be selected. The annotations, which are simply notes following the scientific name, may be expressed by words, sentences, or symbols, or any combination of these. The points which one may consider may well include such items as the following: kind of plant, tree, shrub, herb, forb, weed, etc.; the growth form of the plant, which may conveniently utilize Raunkiaer's method of expression, although other methods are available; the duration; various conditions of growth which are not included in the growth form itself, such as shallow-rooted or deep-rooted; any points that may seem of importance regarding the various parts of the plants, as the condition of the leaves, whether simple or compound, arrangements; color of flowers; quantity and duration of flowers, attractiveness for insects; types of fruit and fruit dispersal; number of individuals; the association in which the plant regularly occurs and its ecological position therein; evidences of spread or retraction of area, successional indications, and abundance. While various of these may be used, the ones most frequently found are the duration, the growth form, the abundance, successional relationships, and occasional remarks where special points need to be recorded. The more important the plant, the greater space it should occupy in the annotated list. Rare plants are sometimes omitted altogether or lumped at the end with a statement: "The following plants have been found once or twice but show no indications of ecological importance." Where a rare plant is ecologically significant, it should certainly be included in the annotated list. Additional items may be added as necessitated by the particular problems.

Secondary Annotated Lists. In making an ecological study of an area where associations are described in some detail, it is a good idea to include in a description a brief annotated list of at least the dominant species and possibly also the important secondary species. Where successional relationships are indicated and the number of invaders or relics is not too small, they may be put in a list form, or if only a very few are indicated, one after another in the text.

Special Use List. If there are any specialties concerned with

the study, as for example, plants which might be used for ornament, drug plants, poisonous plants, grazing plants, noxious weeds, water plants, parasitic plants, etc., such special listings may be included in the paper. The great advantage of listing is that it enables one to make comparisons readily, much easier to the eye than if one has to find the various names in the text, especially if the lines are long.

VEGETATION FORMULA

The setting up of vegetation formulas does not have the attention of ecologists which it deserves, probably as a result of the general lack of advanced mathematical training among ecologists. While mathematical expressions of vegetation are desirable, no really satisfactory expression that is very usable has as yet been developed. C. Dudley Stamp ("Vegetation formula," *Nature*, **123**:833–834. 1929) has made a start in that direction by dividing plants into a few growth forms and by counting the number of individuals in each of the growth forms on a standard area. The separation of growth forms gives importance to trees, for instance, because the number of ground plants might exceed that of the trees and yet the dominant plants of forests are trees. The use of unit areas for standard methods of counting does yield formulas as indicated below and these may be compared with formulas derived not only from region to region, but also from associations within one region. A better formula will doubtless come in time, but it will be developed in advanced rather than in elementary ecological work.

Two examples of vegetation formulas developed during a study of northern Michigan bogs (*Ecol. Monog.*, **12**:252) are as follows: that of the *Carex lasiocarpa* association, illustrating an early bog stage, and that of the Thuja association, the end of the bog succession.

C. lasiocarpa association: $0A + 0F + 17{,}500H + 3{,}500{,}000G\underline{a}(1) + 0C$ by which is meant: per hectare, no trees; no shrubs; 17,500 herbs not grass nor grasslike; 3,500,000 grasses or grasslike plants, in this case the sedge, *C. lasiocarpa*, shown by "$\underline{a}$"; the underline meaning that this Carex is a dominant species in

the association and (1) meaning that it averages about one meter high; and no cryptogams.

Thuja association: $33{,}000A\underline{f}^{c}(20) + 100A'' + 20{,}000Fx + 32{,}300F'x + 218{,}000\,Hx + 90{,}400G + 500C + C'0.01\text{–}0.3$ by which is meant: per hectare, 33,000 trees of f, which is *Thuja occidentalis*, an evergreen conifer and the dominant species in the association, averaging about 20 meters high; 100 seedlings of invading trees; 20,000 high shrubs of miscellaneous species not dominant; 32,300 low shrubs of various species; 218,000 herbs of various species, none dominant; 90,400 grasses and sedges; 500 ferns; and a moss ground coverage of from 1 to 30 per cent.

NOMOGRAPHY[1]

The application of nomography to the calculation of certain ecological data is a particularly desirable exercise for more advanced students, although the method of employing it is usually understood even by beginners. While nomograms may be set up for interrelations of many functions in ecology, one of the simplest is illustrated in *Ecology* (**21**:505–508. 1940) where W. E. Gordon set up copyrighted nomograms for the conversion of psychometric data into expressions of vapor pressure, dewpoint, relative humidity, or vapor-pressure deficit. Since the nomograms are made for the principal average barometric pressures to be found in the United States they may be employed anywhere except on the tops of the highest mountains. With the nomograms available, the use simply involves placing a straight edge so as to pass through the two known points. Where the straight edge crosses one or another of different functions, the answer is the reading; *e.g.*, in the calculation of relative humidity the straight edge will be placed to touch the dry-bulb temperature for the average pressure of the place and the wet-bulb temperature also for the average pressure of the place. The extension of the line into the relative humidity column will give the desired relative humidity.

[1] A system of geometric representation of interdependences of variables, in which, for example, graduated lines representing variables are so arranged on a flat surface that a line passing through two known points which have been determined will give the corresponding value of additional variables at the point of intersection with their lines.

REPORTS

The making of reports on field studies is a valuable phase of student work. Written reports may be but the answers to questions given by the instructor; nevertheless, there is great advantage in having the reports more formal. As a forerunner to the writing of a thesis or for writing for publication, the training is obvious. The writing of formal reports necessitates orderly presentation of data. At this point the student may become aware of gaps in his knowledge and thus be led to further investigation.

As an aid to formal, orderly presentation of the material of an ecological study, a general outline is given below. It is not the intention that every item in this outline should be covered in each written report, but this outline will serve to indicate the items which most frequently occur. Likewise it is not essential that the exact order of items should necessarily be followed. Different subjects require different procedures.

It is advantageous for the student to read over a few ecological papers to notice arrangement, subdivision of the subject matter, and ways of expression before writing his own paper. This should never prevent the student from developing a style of his own, but it may help to round off too rough edges. After the first papers have been handed in it is a good practice to go over them with the students, individually and alone, the teacher making such comments as come to mind in the presence of the student, but without assigning to the student a mark or grade for this first paper. Should the paper be much out of line the student should be asked to improve, correct, or even rewrite, as the situation suggests.

GENERAL OUTLINE FOR ECOLOGICAL WORK

(Select as necessary from the following items)

I. Title.

II. Table of Contents (not always essential but often quite useful).

III. Introduction.

A. Work—what? when? where? why? under whose direction?

B. Acknowledgments of help, laboratory and field facilities, courtesies, etc.
C. Photographs.
D. Trips.
E. Collections, where deposited.

IV. Location of Area.
A. Geographical (maps—general and special detailed).
B. Geological (maps, if available).
C. Ecological.
D. Historical considerations.

V. Factors.
A. Physiographic—exposure, slope, altitude.
B. Climatic—heat, moisture, rainy days, frost, snow, wind, growing season, pressure, special peculiarities.
C. Edaphic—soil, other local factors.
D. Biotic—other plants and animals.
E. Any special additional factors.

VI. Previous Work.
A summary of work applying to the area or similar ones, citing the article or referring to references, literature cited, or to a bibliography.

VII. Methods.
General, but with a detailed description of new methods, if used.

VIII. General Consideration.
A. Of the region in general.
B. Of special places in the region.

IX. Description of Subareas or Sample Plots.

X. Data of Work and Experimentation (separately or incorporated with the above.

XI. Plant Groupings (associations, types, or communities).
A. Ecological structure.
a. Physiognomy or life forms.
b. Layers.
c. Aspects.
d. Ecological peculiarities.
B. Floristics.
Specialized species lists of dominant and characteris-

tic secondary species giving such items as frequency, abundance, vitality, sociability, season, and other items of importance or interest.

XII. Successional Relationships (stages, with species important in each, accompanied by succession diagrams if possible).

XIII. General Discussion (as necessary, leading to general conclusions).

XIV. General Conclusions.

XV. Economic Considerations (whenever possible).

XVI. Summary.

A series of numbered items of specific value, which make it possible for the casual reader to get the main points of the article without having to read it completely. NOTE: Avoid such statements as "Succession was noted." Use "Association *A* is succeeded by Association *B*, in about *x* years"—in other words, use informative statements if possible.

XVII. Complete Annotated Species List.

XVIII. References, Literature Cited—or more rarely, a Bibliography.

XIX. Illustrations, Maps, or Diagrams (here or spread through the text).

XX. Index (if the paper is long, or an index is desirable).

EXERCISES ON THE STRUCTURE AND PHYSIOLOGY OF PLANTS

While this is a field manual, it is very true that an understanding of the anatomy and physiology of plants is necessary for full appreciation of ecological behavior. In addition, when field work is not feasible, students may carry on experiments in the laboratory. Therefore it seems wise to include a group of possible exercises in these fields. For further discussion the student should refer to the standard textbooks and laboratory manuals in the fields in question.

Although the treatment of the material will be in accordance with normal anatomical and physiological methods, the material itself upon which to work should be selected from the field for its ecological significance.

These exercises may be grouped under three main headings: gross or external anatomy, internal anatomy, and physiology.

Exercise 57. External Anatomy

Among the many possible studies dealing with the external anatomy of plants, most are concerned with finding examples which illustrate lists of characteristics. In so far as is possible examples should be selected from the flora of the region in which the work is being done.

The directions given are intentionally brief. For more detailed consideration the student is referred to pages in "Ecology" by H. C. Cowles, as revised and enlarged by George D. Fuller, 1931.

Exercise 57a. Roothair production in moist air and water. Germinate some seeds between pieces of moist blotting paper held over a tumbler of water by a wide-mesh screen, so that the roots may grow down into the water. Observe the location of the roothairs. Also germinate seeds, such as radish, in loose, moist sand. After 3 to 4 days, gently pull up the plants, noticing

the sand grains held by the roothairs. (Cowles, pages 7 to 12.)

Exercise 57b. Adventitious roots and polarity. Cut willow branches two or three years old in 15- to 20-centimeter lengths. Suspend in various positions in a moist chamber, or set right side up and upside down in a tumbler of water. Observe the occurrence and position of adventitious roots and shoots after a few days. Explain. Sketch. (Cowles, pages 19 and 262 to 266.)

Exercise 57c. Mosaic of leaves. Find plants which make rosettes on the ground. Observe how the leaves are arranged so that each receives a maximum of sunlight. Observe maple twigs to see how the different petiole lengths permit a maximum leaf exposure to sunlight. Sketch each. (Cowles, pages 57 to 66.)

Exercise 57d. Trichomes, cutin, wax, and other surface features. Observe several leaves and stems to find different types of hairs, including stinging hairs; also scales, glands, and other protuberances and coverings. Sketch several. (Cowles, pages 83 to 93.)

Exercise 57e. Leaf variation. Collect 50 to 100 leaves from a given plant, or from different plants of the same species in the same and different habitats, to make comparisons. Measurements of length and breadth or other features may serve to set up ratios for statistical analysis. (Cowles, pages 105 to 123.)

Exercise 57f. Juvenile vs. mature leaves. Make collections of the cotyledonary leaves, succeeding young leaves and mature leaves of a few different plants and compare. Sketch.

Exercise 57g. Carnivorous plants. If carnivorous plants are available make sketches to show the animal-catching structures. (Cowles, pages 131 to 134.) Study also "Insectivorous Plants" by Charles R. Darwin, 1889, and "The Carnivorous Plants" by F. E. Lloyd, 1942.

Exercise 57h. Physiognomy of plants: silhouettes. Make outlines or shadow pictures of various plants, especially of the dominant species. If trees, do this in summer for mass effect and in winter for system of branching. Assign to the proper life forms (see Exercise 51 and Fig. 15).

Exercise 57i. Tendril coiling and other means of climbing. Observe tendrils that are developing, others that have become attached. Sketch carefully. If possible, watch the process of tendril attachment and subsequent coiling. Cucurbits, as Sicyos

and Echinocystis, make excellent plants to utilize. (Cowles, pages 154 and 168 to 173.)

Exercise 57j. Stems and leaves as reproductive structures. Through observation and reading, list with sketches, if possible, several examples of rhizomes, bulbs, tubers, corms, slips, etc. (Cowles, pages 184 to 195.) Leaves of Bryophyllum, Kalanchoe, Sansevieria, and Saintpaulia are among the best for class experimentation. (Cowles, pages 151 to 152.)

Exercise 57k. Ectotropic mycorhiza. Explore the roots of various plants, especially trees, to discover which are covered with such fungi. (Cowles, pages 307 to 315.)

Exercise 57l. Anemophilous and entomophilous plants. Both by observation and sketching, together with recourse to botanical manuals, list a number of plants of each of these types. With which are the allergies, such as hayfever, associated? (Cowles, pages 344 to 377.)

Exercise 57m. Sequence from bud to flower to fruit. Observe over a period of a few days, sketching as you observe, the position, shape, and size of buds as they appear. Continue through the flowering and fruiting stages. Yucca and Phryma are two particularly satisfactory plants to work with. (Cowles, pages 385 to 390.)

Exercise 57n. Dispersal means and mechanisms for fruits and seeds. Make lists with sketches of various types of fruits and seeds to bring out the means or mechanism of fruit and seed dispersal. (Cowles, pages 434 to 445.)

Exercise 57o. A bisect, excavation of a root system. Make a trench sufficiently deep and wide alongside of a plant in nature or an experimental plant. With ice pick and needle carefully tease out the root system, making sketches the while to show its conformation. Repeat with other plants and compare. (Weaver and Clements, pages 39 to 42.)

Exercise 58. Internal Anatomy

A study of the internal structure of parts of plants brings out many examples that are ecologically significant. Before studying from this standpoint it is necessary to prepare the specimens, section, and mount the sections for microscopic study. If per-

manent mounts are made they can be stored for use upon short notice any time later.

For the technique of slide preparation, a most excellent book is "Plant Anatomy" by W. C. Stevens, the fourth edition, published in New York in 1924.

A more recent book on this subject is "Elements of Botanical Microtechnique" by John E. Sass (McGraw-Hill Book Company. 1940). In "An Introduction to Plant Anatomy" by A. J. Eames and L. H. MacDaniels (2d ed. McGraw-Hill Book Company. 1947), Chap. 14 deals exclusively with the subject of ecological anatomy.

After the technique of making and studying slides has been learned in the plant-anatomy or plant-histology class, much of the material which may be used can be selected for its ecological bearing; thus these subjects may supplement each other. While any part of the plant may be studied with a view to ecological relationships, some are especially suitable for that purpose.

Proper sections of the various tissues of different plants should be prepared, stained, and mounted ready for study under the compound microscope. Drawings or photomicrographs should accompany each such study.

It is most desirable to have materials of the same kinds of tissues from diverse ecological situations so that comparisons may be made and thus the effects of variations in the various factors of the environment brought out.

Following are a number of such possibilities from which selection may be made.

Exercise 58a. Structure of xerophytes, mesophytes, helophytes, hydrophytes, and halophytes with respect to leaf structure (Cowles, Chap. II). Epidermis (Cowles, page 83); mesophyll (Cowles, pages 46 to 55); stomatal structure and arrangement, protection, and mechanics (Cowles, pages 71 to 79); appendages, trichomes, scales; glands, hydathodes, inclusions; sun and shade leaves; leaves of succulents and fleshy xerophytes (Cowles, pages 141 to 150); absciss layers (Cowles, page 98); and the rolling of leaves.

Exercise 58b. Structure of stems (Cowles, Chap. III) *and leaves* of different ecological types with respect to amount and location of conducting tissue (Cowles, pages 195 to 211); amount and lo-

cation of mechanical tissue (Cowles, pages 211 to 219); latex tubes (Cowles, pages 235 to 238); resin ducts (Cowles, pages 238 to 240); air chambers and aerenchyma (Cowles, pages 67 to 71).

Exercise 58*c*. *Structure of bark* of different ages and different types (Cowles, pages 219 to 224).

Exercise 58*d*. *Structure of roots,* including roothairs, of different ecological types (Cowles, Chap. I).

Exercise 58*e*. *Structure of haustoria of parasites,* as Cuscuta (Cowles, pages 283 to 291).

Exercise 58*f*. *Structure of glands of carnivorous plants,* as Drosera (Cowles, pages 131 to 134). (See also Exercise 57*g*.)

Exercise 58*g*. *Structure and position of endotropic mycorhiza* (Cowles, pages 307 to 315).

Exercise 58*h*. *Annual increments or "rings"* in the wood of different species under different ecological conditions. (See also Exercise 56.)

Exercise 59. Physiology

There are many exercises or experiments which may be conducted with individual plants and are commonly a part of the course in plant physiology. Since several such experiments show reactions of plants to environmental factors, the ecological bearing of such experiments is obvious. Some of these experiments may well be included even in field courses in ecology, as time and equipment permit.

Detailed directions for setting up and conducting experiments in plant physiology are found in many laboratory manuals, two of which may be cited as follows:

LOOMIS, W. E., and CHARLES A. SHULL, "Methods in Plant Physiology," McGraw-Hill Book Company, Inc., New York. 1937.

MEYER, B. S., and D. B. ANDERSON, "Laboratory Plant Physiology," Edwards Bros., Inc., Ann Arbor, Mich. 1940.

A list of the most suitable such experiments, which may be carried on in the field or which require materials obtained in the field, together with the essential directions, follows. A reference to Loomis and Shull for more detailed directions is given, when possible:

Exercise 59a. The amount of water contained in various tissues of different plants. Obtain by weighing the parts in question, drying in the air or in an oven maintained at just over 100°C to constant weight and calculating the part that was water.

Exercise 59b. The relation of water to growth. Potted plants are given different amounts of water and the results recorded (Loomis and Shull, Exp. 3).

Exercise 59c. Water and germination. Hard seeds, such as honey locust (Gleditsia) or Kentucky coffee tree (Gymnocladus) are soaked overnight, to eliminate any that may swell, and dried. Two lots of the remaining seeds—one of which is used as a control, while the seeds of the other lot are filed through the seed coats—are put between moist blotting papers and observed in 3 to 5 days to note any germination.

Exercise 59d. Available-moisture or wilting coefficient. Seeds of a given kind of plant are grown in pots containing different types of soil, as sand, loam, silt, clay, until they are obviously established, whereupon water is withheld. As soon as the plants wilt, take out a sample of soil from around the roots, weigh, dry to constant weight, and calculate the amount of nonavailable water (Loomis and Shull; a more elaborate experiment with salt is Exp. 8).

Exercise 59e. Guttation. To demonstrate most easily grow young grass plants to a height of about 5 to 8 centimeters. Water the pots with warm water and cover pot and plant with a cold bell jar and observe (Loomis and Shull, Exp. 11).

Exercise 59f. Transpiration values of various species in the same and in different habitats or associations. Arrange the plants in pots or potometers so that water is lost only from the leaf surface, weigh at intervals, measure the extent of the leaf surface (multiply by two if stomates are on both surfaces), and calculate the rate of water loss per square unit of leaf surface per hour (Loomis and Shull, Exps. 19 to 21 and others in Chap. III).

Exercise 59g. Condition of the stomates. With a quick-penetrating oil, as benzene, xylol, or turpentine, test the openness of the stomates. The quicker the penetration, the more open the stomates (cf. Meyer and Anderson, Exp. 51).

Exercise 59h. The chemicals present in the plant and in its ash. For more advanced students, the presence of the kinds and

amounts of various chemical elements in plants from various habitats may be determined in a chemical laboratory, not usually in the field (Loomis and Shull, Exps. 35 to 39; also Chap. IV, Essential Elements, Exps. 40 to 44).

Exercise 59*i*. *Freezing point of plant juices.* From a determination of the freezing point of plant juice learn the osmotic strength of the sap (Loomis and Shull, Exp. 54).

Exercise 59*j*. *Chlorophyll and photosynthesis.* The relationship between chlorophyll and photosynthesis; amount and kinds of light, etc. (Loomis and Shull, Exps. 74 to 77, 83, and 84; Chap. VII; Cowles, Chap. II).

Exercise 59*k*. *Regions and rate of growth.* Mark in millimeter or other squares the surfaces of young leaves and, in short lines, stems and roots for a distance back from the tips. Observe after intervals of a few hours or days. Learn the difference in the region of stem growth between monocots and dicots (Loomis and Shull, Exps. 135 to 137; Chap. XII).

Exercise 59*l*. *Movement of plants.* The effect of different factors upon the growth of plants: gravity (Exps. 146 and 147), light (148), water (150); the twining movements (152), sleep movements (154); shock movements (153), etc. (Loomis and Shull, Exps. 146 to 154).

Exercise 59*m*. *Etiolation.* Effect of growing normal plants in the dark (Loomis and Shull, Exp. 157).

Exercise 59*n*. *Polarity.* Expose 20-centimeter pieces of willow branches, placed in various positions, to moisture and observe at intervals (Loomis and Shull, Exp. 159. Cowles, pages 262 to 266).

Exercise 59*o*. *Xerofotic movements.* Observe the position of legume leaflets in the middle of a hot, sunny day and contrast it with the position earlier and later in the day and at night (cf. F. C. Gates, "Xerofotic movements in plants," *Bot. Gaz.*, **61**: 399–407. 1916).

Exercise 59*p*. *Digestion experiments with carnivorous plants.*

Exercise 59*q*. *Effects of certain chemicals on plants; weed killers.* Using different "weed killers," as Weedone; 2,4-D; etc., apply as directed and observe the effects on a bit of natural vegetation at intervals. Repeat on weeds and garden plants under cultivation.

SOIL CHARACTERISTICS

In working with plants in the field the characteristics of the soil constitute an important part of ecological study, especially in view of the fact that the plant cover plays a dominant role in the building of the soil itself. It is therefore important that possible exercises dealing with the soil be included.

For a concise account of soil, its development, and its importance in human economics, the beginning student is referred to "Soils and Men," 1938 Yearbook of the U.S. Department of Agriculture. A recent book dealing with the soils of forests is "Forest Soils" by H. J. Lutz and R. F. Chandler, Jr. (John Wiley & Sons. 1946). For the classification of local soils, recourse had best be had to local soil maps and field studies published by state or national departments of soils, if such are available for the area in question.

For use in studies of the soil itself the best guide is "Soil Characteristics, a Field and Laboratory Guide" by Paul Emerson (McGraw-Hill Book Company. 1925). Page references to this book are included in connection with the exercises listed below.

In Weaver and Clements, soil in relation to plants and vegetation is dealt with in Chap. VIII and in parts of Chaps. IX–XI and XVII. In Braun-Blanquet and Fuller and Conard, *op. cit.*, Chaps. VI–X are devoted to consideration of the soil.

Samples of soil may be obtained by digging a hole or a trench in the ground and the samples scooped out from the sides. A posthole auger is more expeditious for digging deeper holes. In special work a regular soil-sampling kit with sampling tubes is desirable.

SOIL DESCRIPTIONS

I. In the Field.
  A. General considerations.
    a. Origin.
      (1) Geological formation.
      (2) Residual.
      (3) Cumulose.
      (4) Glacial.
      (5) Eolial.

(6) Alluvial.
Etc.

b. Native vegetation if possible—mainly limited to prairie or timber.

c. Topography—features or lay of the land.

d. Natural drainage, whether efficient or not.

(1) Geological age.

(2) Terraces.

e. Organic matter—generally estimated by color of the soil.

f. Agricultural value and productive capacity.

B. Specific considerations.

a. Profile or layers—changes in soil at various depths.

(1) Azonal.

(2) Zonal.

i *A* layer. Layer of accumulation of leaves, debris, etc., and also layer of maximum leaching.

ii *B* layer. Layer of maximum utilization by roots of plants.

iii *C* layer. Parent material, weathered but not yet built up into soil, sometimes absent.

iv *D* layer. Underlying stratum.
Note depths where change in color, structure, or texture occurs.

b. Color of profile at different depths.

c. Structure or granulation of profile at different depths.

(1) Texture.

(2) Porosity.

(3) Friability.

(4) Plasticity.
Etc.

d. Physical composition (class of soil) of profile at different depths. An estimation of percentage composition of the different-sized particles.

II. In the Laboratory.

A. Reaction, pH—sometimes determined in the field.

B. Chemical analysis—analysis of the various minerals and elements.

C. Organisms.

Some exercises that may be conducted with soils follow. Page references are to Emerson, cited above.

Exercise 60*a*. *Mechanical analysis* (page 15). Take at least 500 grams of dry soil, break the concretions with a *rubber* pestle, sift through a series of soil sieves, the larger first, by jarring, and weigh the separate portions. Do not rub through any sieve. The finer silts and clay require separation by settling in water for different lengths of time, or centrifuging.

Exercise 60*b*. *Soil colloids*. These remain in suspension after Exercise 60*a* above is completed.

Exercise 60*c*. *Apparent specific gravity*. The ratio between the weight of a unit volume of water-free soil and the weight of the same volume of water. No account is taken of pore or air space.

Exercise 60*d*. *Actual specific gravity* (page 24). The weight of the water-free soil divided by the weight of the water displaced.

Exercise 60*e*. *Internal surface area* (page 25). Combined surface area of each of the soil particles. Prepare soil fractions. Determine the number of particles in 0.01 gram of each of the water-free samples. Find the average diameter of the particles in each fraction and calculate the surface, as spheres.

Exercise 60*f*. *Soil moisture*. Per cent of moisture based on dry weight (page 26). Hygroscopic water determined by heating known weights of samples to constant weight at temperatures of 110°C for 8 hours or more (page 27). Capillary water: Fill a tube or lamp chimney with the soil, firmly settled by allowing the tube to bounce-drop a short distance several times. Set in a pan of water. Record the ascent and weigh after the water has reached the surface (page 28).

Exercise 60*g*. *Gravitational water* (cf. also page 29). Using a cylinder nearly closed at one end, saturate a tube of soil with water. Place the cylinder upright and, if necessary, add water until dripping takes place. When dripping stops, remove a sample from the center of the soil and determine the water content. This is known as the *holard*. Grow plants in this soil until well established, whereupon withhold water until the plants wilt. The water content after wilting, *i.e.*, water which the plants have not re-

moved from the soil is known as the *echard* and that utilized by the plants as the *chresard*.

Exercise 60*h*. *Porosity of the soil*. Using the results from Exercises 60*c* and *d*, substitute in the following equation:

$$\frac{\text{Real specific gravity} - \text{apparent specific gravity}}{\text{Real specific gravity}} = \text{porosity}$$

Exercise 60*i*. *Air flow through soil*. The special apparatus and the directions are given on page 32 in Emerson.

Exercise 60*j*. *Carbon dioxide of soil air*. The special apparatus and directions are given on page 32 of Emerson.

Exercise 60*k*. *Soil temperatures*. See directions under Exercise 37 of this manual.

Exercise 60*l*. *Heat conductivity*. Embed in the soil a copper pan of water so that it can be heated to a temperature of about 95°C and maintained at that temperature. Have thermometers at stated intervals (7.5 centimeters) in the surrounding soil. Read at intervals of about 10 minutes.

Exercise 60*m*. *Shrinkage of soil* (page 40). Place a block of moist soil on a piece of wax paper, measure, and after a few days' exposure to air, remeasure.

Exercise 60*n*. *Organic matter* (page 40). Weigh a sample of soil, dry in an oven, reweigh, ignite, and weigh the ash. Calculate the amount of organic matter on the basis of the ovendry weight.

For more advanced work in studying soil humus, soil colloids, the various minerals, bases, and elements in the soil, the adsorption of various compounds and the study of soil fertility, the more advanced student should consult standard chemical and soil books for methods of procedure.

EQUIPMENT FOR FIELD EXERCISES

Balance
Calipers, small (0 to 50 millimeters)
  tree
Camera
Compass, drawing
  pocket magnetic
  magnetic, on a tripod for surveying
Davis peat borer
Drying oven
Grass clippers
Hand ax
Handlevel
Iron pipe, scrap in 5-foot lengths for permanent quadrats
Level
Meterstick
Notebook in aluminum cover
Pantograph
pH-meter
Planetable on tripod
Planimeter
Pliers
Raingage
Sampler, bottom, for lake work
Sash cord in 50- and 100-foot lengths with wire loops at each end
Secchi disk for work in water
Sighter for surveying
Soil auger
Soil sampling kit
Soil sieves in a set
Spade
Squares of cardboard or celluloid, 10 centimeters on a side
Stadia rods (sticks 2 and 3 meters long, 7.5 by 2 centimeters

wide and thick, painted white, will serve the purpose. Alternate 10-centimeter intervals in black are painted halfway across the stick. The line for every half meter is carried clear across the stick.)

Stakes of creosoted wood, 12 by 1 by 1 inches
Surveyor's pins
Tape, steel in 100-foot length
Thermometer, ordinary
  for wet and dry bulb
  Nagretti and Zambra, for lake work
  soil set
Thermocouple outfit
Triangle, 45°
Twine, stonemason's or stout twine
Wind meter

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